STABILITY ANALYSIS OF OPEN PIT SLOPE USING FLAC

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
in
Mining Engineering

By

SUDARSHAN PRADHAN
110MN0400

Department of Mining Engineering
National Institute of Technology
Rourkela-769008
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Under the Guidance of

DR. DEBI PRASAD TRIPATHY

Department of Mining Engineering
National Institute of Technology
Rourkela-769008

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National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the thesis entitled "**Stability Analysis of Open Pit Slope using FLAC**" submitted by **Sri Sudarshan Pradhan**, Roll No. **110MN0400** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Dr. Debi Prasad Tripathy

Date:

Professor, Department of Mining Engineering
National Institute of Technology
Rourkela-769008

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My heart pulsates with the thrill for tendering gratitude to those persons who helped me in completion of the project.

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I am thankful to mine officials of Samaleswari OCP who have extended all sorts of help for accomplishing this undertaking.

An assemblage of this nature could never have been attempted without reference to and inspiration from the works of others whose details are mentioned in reference section. I acknowledge my indebtedness to all of them.

At the last, my sincere thanks to all my friends who have patiently extended all sorts of help for accomplishing this assignment.

Date:

Sudarshan Pradhan

110MN0400

ABSTRACT

Stability analysis of slopes forms a vital component of various opencast mining operations throughout the life cycle of the project. A deterioration of slope in the area being worked of mine can leads to a severe economic safety as well as great economic catastrophe. The elementary failure conditions are both diverse & complicated. These failure mechanisms are largely controlled by local geology status, which are practically unique to a specific location of rock mass. In the recent years also the method of designing slopes are absolutely based on field knowledge and the approaches can be made through safe designing of slopes.

The aim of the project is to carry out tri-axial test for estimating cohesion, angle of internal friction of coal samples and stability analysis of slope by finding out the factor of safety, using numerical modelling software viz: FLAC/SLOPE and OASYS by varying different bench parameters.

Field visit was conducted to collect coal lumps and valuable mine data. In the laboratory, coal samples were prepared by coring and tri-axial test was performed. Using tri-axial test data cohesion and angle of internal friction was found out by RocLab program.

Numerical modelling was carried out by using FLAC SLOPE and OASYS software for finding the factor of safety. It was observed that the factor of safety varies from 4.34 to 5.37 in FLAC SLOPE and from 4.37 to 5.43 in OASYS for the slope angle of 35^0 to 70^0 with an interval of 5^0. The factor of safety increases with increase in the value of cohesion and angle of internal friction.

The factor of safety varies on changing the search radius and angle of rotation in case of OASYS, whereas in case of FLAC SLOPE, the factor of safety changes on changing the resolution of the numerical mesh.

KEYWORDS: FLAC SLOPE, OASYS, Cohesion, Slope stability, Angle of Internal Friction, Factor of Safety.

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INTRODUCTION

CHAPTER - 1

INTRODUCTION

1.1 BACKGROUND OF THE PROBLEM

Stability analysis of slopes is a very important component in opencast mining operations. It involves larger production and high grade mechanization. Due to the production of huge amount of materials there is a change in the dimensions of the pit i.e. depth, bench height. The change in the dimensions generates difficulties related to stability. Therefore it is very crucial to evaluate the various modes of failures occurring in the bench slope and to take economically feasible steps to reduce, remove and mitigate the risk associated with slope stability as well as to provide a safe and comfortable environment to the manpower & costly machineries employed.

To tackle the problems related to stability numerical modelling software are needed. The software used in this research is FLAC SLOPE and OASYS.

FLAC SLOPE was used for slope stability analysis because it is user friendly software which can be regulated from FLAC's graphical interface (the GIIC). It helps in generating the models for rock slopes as well as for soil slope and gives a proper explanation to their stability condition. In addition to this, FLAC SLOPE is conventional software widely accepted in mining industry.

OASYS was also used for slope stability analysis as it considers the failure surface to be moving in a direction lying in the arc of a circle.

An effort has been made for analyzing and designing of stable slopes in open pit mines using FLAC SLOPE & OASYS and to have a comparative analysis between them.

The aim of this project is to study stability analysis of coal bench slope at Samaleswari OCP located in Jharsuguda, Odisha and to carry out the parametric studies that affect the stability.

1.2 OBJECTIVES OF THE PROJECT

- To carry out the tri-axial test for estimating cohesion and angle of internal friction of coal samples.
- To carryout stability analysis of slope by finding out the factor of safety, using numerical modelling software viz: FLAC SLOPE and OASYS by varying different bench parameters.

CHAPTER- 2

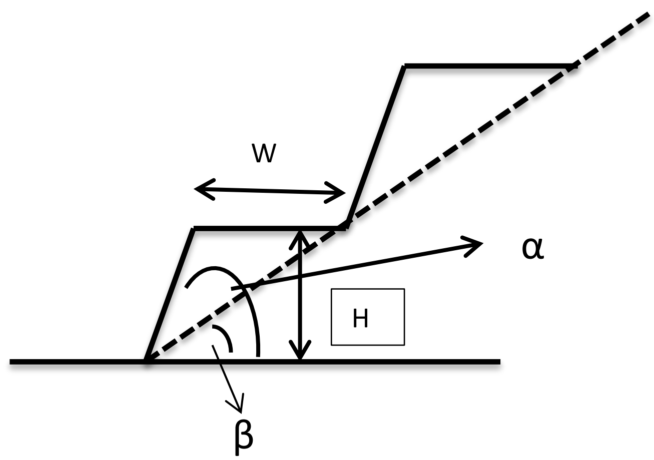
LITERATURE REVIEW

CHAPTER - 2

LITERATURE REVIEW

2.1 ENGINEERING PARAMETERS OF AN OPENCAST MINE [19]

The important engineering parameters of an opencast mine are width, height and slope of open-pit benches and the overall slope of the pit.



W = width of bench

H = height of bench

α = slope of the bench

β = overall slope of the pit

Fig. 2.1 Design parameters of an opencast mine (Source: Singh, 2010)

2.2 OPENCAST MINE BENCHES [19]

2.2.1 Number of benches

The number of benches depends on the following:

- The thickness of overburden
- The thickness of coal seam
- The type of equipment used and their capacity
- Whether multi-seam mining is to be done and if so thickness of the interseam parting

2.2.2 Height of the benches

The following factors affect the height of the bench:

- Nature of ground
- Equipment used
- Working condition

The height of the bench is closely related to the digging height of the excavator. The bench height is usually equal to the digging height of the shovel. In ledge rocks, the height of the broken rock by blasting should not exceed 1.5 times the digging height of the power shovel. In practice the height of the benches in coal mine lies between 12m and 15m.

2.2.3 Slope of benches

Correct determination of slope angle is of paramount importance for a 1^0 deviation in slope angle changes the volume of quarried ground by above 4%. Generally, the angle of slope in sedimentary rock is 50^0 - 60^0. In argillaceous rock it may be 35^0 – 45^0. The high walls of worked out benches have a lesser slope by 5^0 – 10^0, since they continue to serve for a long time. In water bearing rocks both the height of benches and the angle of slope are reduced.

The slope angle of 57^0 in carboniferous strata and of 45^0 in alluvium is normally used for planning purpose. The factors determining the slope angle on the non-productive side of the quarry are berms, opening trenches and the stability of the side walls, whereas on the production side, the width of the working bench and the height of the bench determine the slope.

2.2.4 Width of the bench

The width of the bench usually varies from 40-60m. it should be sufficient so as to accommodate the drill, the transport track, the broken pile of the coal and have some extra ground to permit clear space between the transport road and the broken pile of the rock and also marginal area to facilitate extraction of prepared reserves in underlying bench. The width of the broken pile of the rock can be estimated by the following formula:

$$\mathbf{W_p = C.H.\,B\,(n\text{-}1)} \qquad \mathbf{(1)}$$

Where

W_p = Width of the broken pile of the rock

C = A coefficient usually 1.5 to 2

H = Height of the bench

B = Distance between rows in multi row blasting

n = number of rows

Fig.2.2 Circular failure in highly weathered, granitic rock (on Highway 1, near Devil's Slide, Pacifica, California). (Source: Rock slope engineering, 4th edition by Duncan C. Wyllie and Christopher W. Mah,)

2.3 SLOPE STABILITY

In the broad sense we can say that the slope stability problem is a major challenge encounter by most of the Open pit mining industries. In this field of slope stability , encircles the analysis of the dynamic and static stability of the slope in open pit mining.

The stability problem can be further divided into two major categories, namely:

(i) Local Stability Problem

(ii) Gross Stability Problem

2.3.1 Local stability Problem

This Problem is generally encountered when a much smaller volume of material comes down the slope. This failure type at a time generally affects two or less benches by virtue of jointing of shear plane, erosion associated with slope due to surface drainage, and also because of designated slip-erosion.

2.3.2 Gross stability problem

Gross stability Problems involves when a large volumes of materials when a large volumes comes down the slope. This type of Problem occurs as the result of giant Rotational kind Failures and includes Rock and Soils that are weathered.

2.4 DIFFERENT FACTORS AFFECTING SLOPE STABILITY OF OPEN PIT [1] [17]

Whenever the Slope stability is concern, it is mainly determined by geometry of the surface and designated Slip- horizon. There are many factors which greatly influence the stability of the slope.

Some of the most influencing factors are as follows:

- Slope Geometry
- Geological Structure (Geology)
- Ground Water Table
- Lithology
- Dynamic Forces
- Methods of Mining and Equipment used
- Angle of Internal Friction (ø)
- Cohesion (C)

2.4.1 SLOPE GEOMETRY [6]

Slope Geometry plays an important role in case of Slope Stability. It is one of the most essential parameter that affects the slope stability to a great extent. Bench height, bench width, overall slope angle & Area of failure surface are the basic geometrical slope designing parameters. As we go on increasing the bench height and slope angle, it adversely affects the slope stability.

With increasing the overall slope angle it increment the likely intensity of growth of any failures to back surface of the crests expands & this is to be recognized, so as to avert the ground deformation at mine peripheral area.

As per the Directorate General of the Mine Safety (DGMS), 45^0 is the proposed overall slope angle in the slope stability design process for secure.

The arc of the slope possesses deep consequences on the instability of the slope. Hence it is much necessary to avoid the convex sections slopes in the design process. Less stability is generally associated with steeper and higher height slopes.

Different bench parameters are shown in the Fig.2.3 (e.g. overall slope, bench, ramp, face, toe etc.)

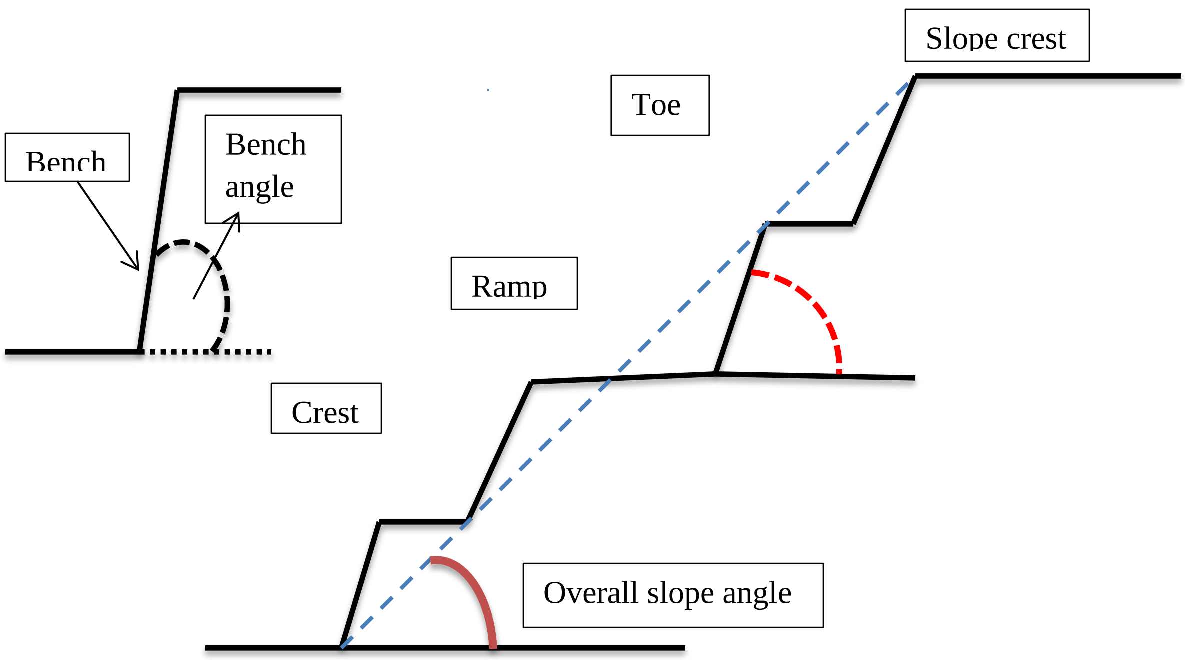


Fig.2.3 Diagram showing Bench, Toe, Ramp, Bench angle, Crest (After Coates, 1977, 1981)

2.4.2 GEOLOGY & GEO-LOGICAL STRUCTURES [14]

Geology is nothing but the dip and strike of the deposits to some extent & Geo-logical structures are the discontinuities associated with them like faults, joints, folds etc. Geological structure that affects most to the stability of the slope in open cast mines is listed below:

- Magnitude and the direction associated with dip
- Shear zones associated within the formation.
- Presence of geological discontinuities like joints
    i) It reduces the shear stability
    ii) Changes penetrable property
    iii) It acts as a sub-surface drain and plain of failures

- Presence of faults
    i) It provides a plane of failure
    ii) It acts as a ground water channel

Fig. 2.4 Various form of the faults & joints (After Nordlund & Radberg, 1995)

Slope instability develops if strata dip towards excavations. The failures in rock may occurs along pre-existing discontinuity structures, or may be through the unbroken material or onward a surface which developed slightly along intact material & somewhat on the discontinuities ,which may leads to instability in the rock slope. It may be noticed that the localized strata steepening is critical phenomenon, for the slope stability. If the clay bands or some other materials come in between the two rock bands, that decreases the cohesion between the both surfaces, and then the strength is hindered. Bedding planes also provides a surface of instability.

Also strength of slope depends factors given below:

- Shear strength available along the surface under failure
- Their orientation near surface in relative to slope
- Pressure associated with the surface because of water

The shear strength which can be assembling on that surface depends on the functional properties of the surface as well as on the effective stress that is transmitted to the surface normally. Joints may be creating a location which may merge many joints & contribute a link over surface.

2.4.3 GROUND WATER

Presence of this may cause the following problems:

- It changes the cohesion and frictional parameters associated with the slope
- Also it may reduce the normal effective stress

The expansion in upthrust and drainage forces which has an unfavorable impact on the slope stability is brought on by because of vicinity of the ground water. Due to the physical & chemical effects of pore water pressure on the joint filling materials, the friction & cohesion of the discontinuity surface may alters.

Physical effects is associated with uplift of the joint surface, reduces the frictional resistances of the surfaces, which then substantially reduces the shearing resistances along possible failure plane by lessening the impacts of normal stress following up on the surface. Because of physical & chemical impact of water pressure in the pore of the rock, compressive strength diminishes, especially where keeping stress have been diminished all things considered.

2.4.4 LITHOLOGY

Lithology of the rock unit is considered to describe its physical characteristics which are visible at outcrop that includes textures, colour, grain size& composition. It generally formed a basis for subdividing rocks sequence into individual litho-stratigraphic units for the purpose of mapping and correlation between areas.

Rock materials that constitute the pit slope focus the rock mass strength changed by the vicinity of discontinuities, faulting, folding, moreover that old workings & weatherings. A rock slope having low mass strength is by and large portrayed by round, raveling and rock fall instability like the arrangement of slopes in massive sandstone confines stability. The vicinity of alluvium or weathered rock at the surface of pit slopes, by and large gives easier shear strength and which may further lessened if water seepage takes place through these structures. These types of the slopes must be flatter.

2.4.5 DYNAMIC FORCES [2] [14]

The shear stress is momentarily increases due to the effect of blasting & vibration, which may results dynamic accelerations of the materials and increases the stability problems in the slope faces. Due to instability ground motion & fracturing of rock may pre-dominants. Blasting can be considered to be the primary factor which governs the maximum achievable bench face angles.

It has been recognized by Sage (1976) et al., that, the impacts of inadequately & heedless planned blasting might be exceptionally critical for bench stability. Notwithstanding blast harm & back break which decreases the bench face angle, the vibrations from the blasting could potentially cause failure of the rock mass. For small scale slopes, different sorts of blasting systems e.g. smooth blasting, controlled-blasting, etc. have been proposed to diminish these impact connected with vibration and encounters are truly good(e.g. Hoek & Bray, 1981). However for expansive scale slopes, the impacts because of blasting is less, as back break and blast harm of benches have immaterial consequences for the stable overall slope angle. Besides, the high recurrence connected with the blast acceleration of the waves restricts them from showing expansive rock mass consistently, as seen by Bauer & Calder (1971).

Subsequently failure began with blasting is a noteworthy issue for the huge scale slopes. Seismic occasions of low frequency vibration (4-24 Hz) could be risky for vast scale slopes, as the frequency corresponds with the slope frequency & resonance is started. Resonance is a state by which slopes absorbs the energy progressively and deformed with time, until plastic deformation occurs. It has been seen, the several seismic induced failures takes place in the mountain or hilly areas.

Those areas present at high altitudes, sometimes water freezes on the slope face ,which can results in the building up of the ground water pressure behind the faces ,that adds up to the instability of the slope.

Along with these causes, external loading can also play a very essential aspect when they are present in case of surcharge due to dumps on the crest of the benches.

2.4.6 METHOD OF MINING & EQUIPMENT USED

There are basically four methods in which the open cast mines advances, which are listed below:

- Strike cut-this method generally advances in the down dip direction
- Strike cut- this method resembles advances in the up dip direction
- Dip out- mine advances along the strike direction
- Open pit

Strike cut is a technique for mining that any developments in down the dip or up the dip headings. Utilizing the dip cut which progresses on the strike may lessen the length & time that face is uncovered throughout unearthing.

Dip cuts with developments slanted to strike may be utilized to decrease the strata dip into the excavations. This technique by and large utilized for most stable slope & acknowledged as the most stable system for working however it has numerous burdens, in the same way as it experiences the limited handling potential.

The fourth system i.e. Open pit strategy is by and large utilized as a part of instance of steeply dipping seams, because of expansion in the slope height and these are more inclined to substantial chunk/buckling modes of the disappointments in asphalt slope. For the most part overwhelming weight mining machinery is utilized within the open cast operation. This present gear's which heaps on the surface/seats of the open pit gives climb a significant build in surcharge, which thus upgrades the slope countenances to move downwards and accordingly instability happens. Instances of round disappointments in the spoils dump are more professed for this.

2.4.7 ANGLE OF INTERNAL FRICTION (ø)

Usually denoted using "Ø" ,and it is the angle measured in the middle of the normal force(N) and the resultant force(R), which are accomplished when failures simply happens in light of a shearing stress. Tangent (R/N) generated gives the co-efficient of the sliding friction, which is the degree of extent of capability of a unit rock mass or soil which can able to bear a shear stress without undergoing failures. This is chiefly affected by particle size and particle slope i.e. roundness. Particles having easier roundness or vast medium particles size brings about bigger angle of internal friction. It is basically influenced by quartz content. The sand with less measure of quartz held more excellent measures of potassium-feldspar, calcite, plagioclase, and/ or dolomite, and these sorts minerals have by and large higher sliding frictional safety contrasted with that of quartz.

There are several techniques available to find the angle of internal friction in the laboratory. Some of these are Tri-axial shear test, direct shear test.

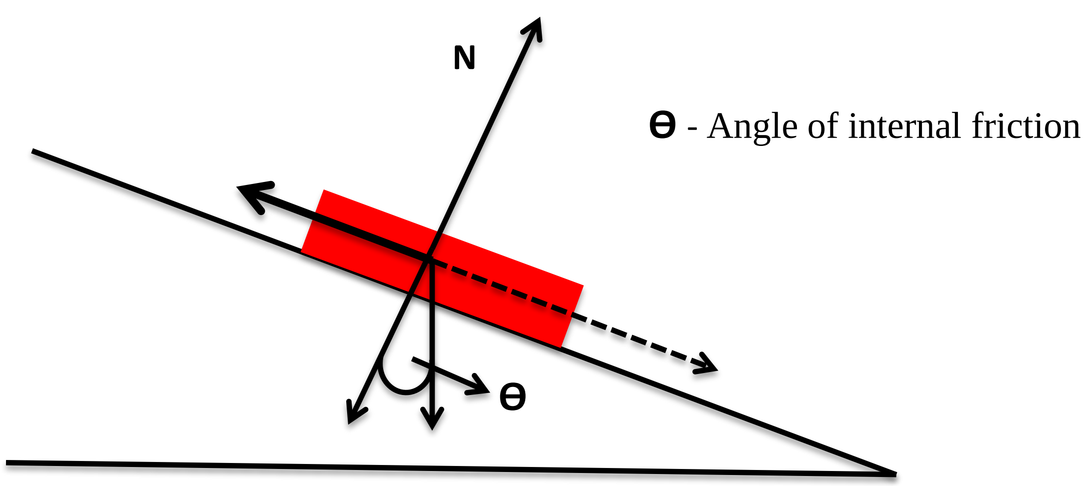


Fig.2.5 Diagram showing angle of internal friction (Source: Google image)

2.4.8 COHESION (C)

Cohesion can be defined as the property of soil or rock which quantifies how effectively it opposes to being distorted or demolished by forces such as gravity due to its own weight. Electrostatics forces in the inflexible compacted clays which are cementing due to Fe_2O_3, $CaCO_3$ and NaCl are the main causes of the true cohesion in case of a soil or rock, but the apparent cohesion is caused because of pressure develops in pore and negative pressure in vein that reply during inexperienced loading. Those ingredients which reinforce the cohesive forces are given bellows:

- Friction: this is one of factor which affects much on stability of bench
- Movements of the materials can be prevented by man-made reinforcements.
- Cementation of grains by the cementing materials like silica and calcite can solidify earth materials in to strong rock

Cohesive factors of the rocks may weakens due to several factors, which are listed below:

- The cohesive strength may weakens due to undercutting in slopes
- Due to the presence of high content of water which may weakens cohesion because abundant water not only adds weight ,but also lubricates (over comes friction) to a mass.
- Vibration coming from sonic booms, blasting, earthquakes which overcomes cohesion & causes mass movement, there by weakens the strength of the rock.
- Substituting augmentation by soaking and shrinkage via airing of water debase quality of cohesion, much the same as substituting extension by solidifying and withdrawal by defrosting. Because of repeating of both extensions which is constantly perpendicular to the surface and constriction vertically by gravity overcomes cohesion coming about with the rock and dregs moving gradually downhill.

2.5 SLOPE FAILURES TYPES [10] [14] [21]

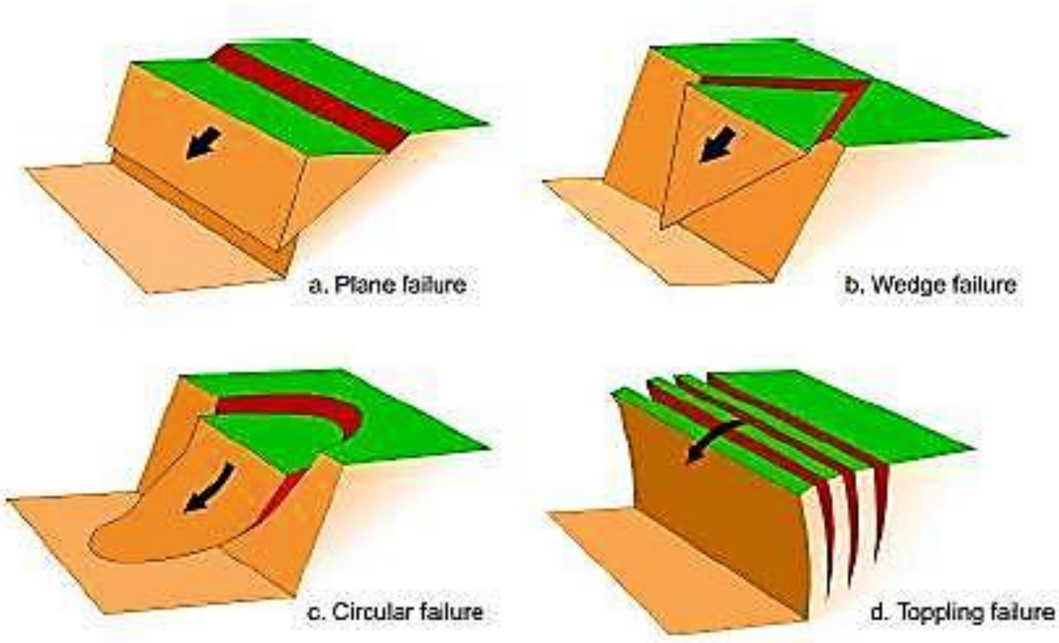


Fig.2.6 Modes of slope failures (Source: Google image)

2.5.1 PLANAR FAILURE

Planar failures are the most common, easiest and simple form of rock slope failures that occurs in the benches. This mode of the failures comes to exist when the discontinuity strikes parallel or relatively parallel as well as steeping at a minor angle intersects the slope face that compels materials over discontinuity to slide.

As we can see in the figure 2.7, the mass/block formed by discontinuity progresses down and out forward a more or less planar or undulating surface. These planar failures can give rise different modes of failures depending on the presence of combinations of joint sets in the sliding plane forming a straight path.

Various factors which affects most and through which the movement can be controlled structurally are:

- Joints
- Alteration in the shear strengths between layers of bedded deposits
- Faults
- Surface weakness
- Overlying weathered rock
- Contact between the firm rock bed
- Bedding flat surfaces

Conditions required for the failures to occur:

(i) Dip of failure planes must be lower than the dip of the slope face and friction angle for the discontinuity must be smaller than the dip of discontinuity (Hoek & Bray, 1981)

(ii) The toe of the failure plane daylight between the toe and the crest of the slope (Hoek & Bray, 1981)

(iii) The strike of the plane of weakness must be within ± 20^0 of the strike of the crest of the slope (Hoek & Bray, 1981)

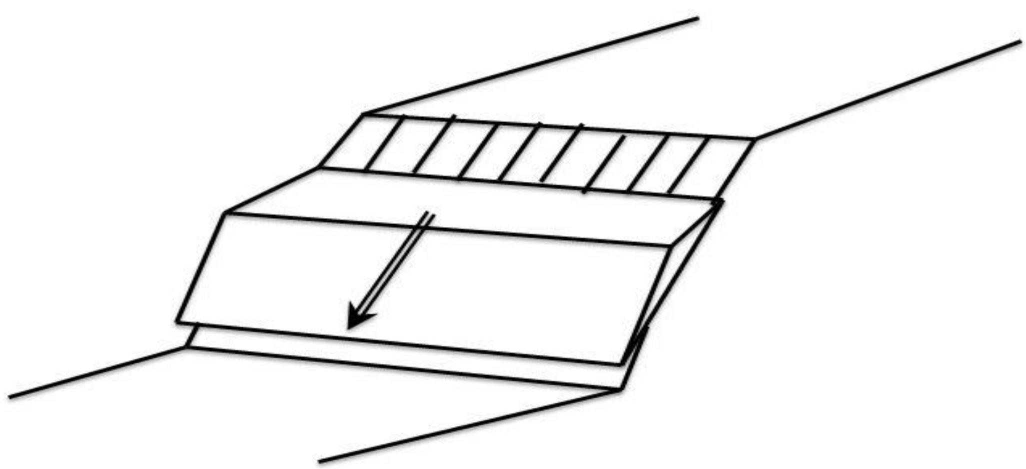


Fig. 2.7 Planar Failure (after Coates, 1977; Call & Savely, 1990)

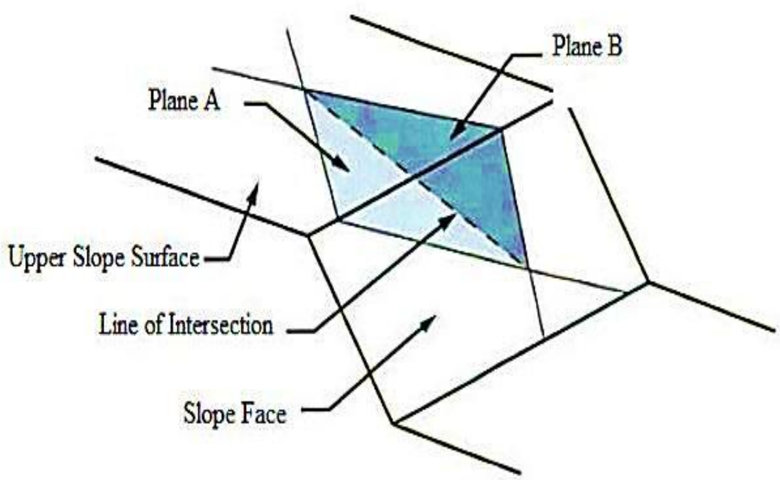
2.5.2 WEDGE FAILURE

This happens due to two intersecting discontinuities. The capability of the wedge failure exists where two discontinuities strike sideways over the slope face and their line of crossing point daylight in the slope face indicated in the Fig. 2.8.

The wedge of rock formed by the intersection of discontinuities will move below the line of intersection and is governed by the following criteria:

- The slant of the line of convergence is fundamentally more stupendous than the angle of internal friction along the discontinuities
- The plunge of the line of convergence daylights between the toe and the crest of the slope.

  This mode of failure is commonly seen individual bench scale but can also contribute the mechanism of failure for an enormous slope where structures are both continuous and considerable. Large scale wedge failure may occur in several benches.



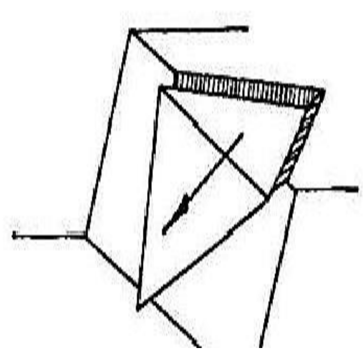


Fig. 2.8 Wedge failure (after Hoek and Bray, 1981)

2.5.3 CIRCULAR FAILURE

This type of deep seated failures occur when a slope is excavated in soil or soft rock formation in which the mechanical properties are not dominated by clearly defined structural features. This mode of failure was first noticed, initially of the century, in Sweden affirmed that the surface of the failure in spoil dumps or soil slopes looks like the state of a circular arc. This failure can happens in soil slopes, the circular technique happens when the joint sets are not extremely decently characterized. At the point when the material of the spoil dump slopes are feeble, for example, soil, vigorously jointed or broken rock mass, the failure is characterized by a solitary discontinuity surface however will have a tendency to take after a circular path.

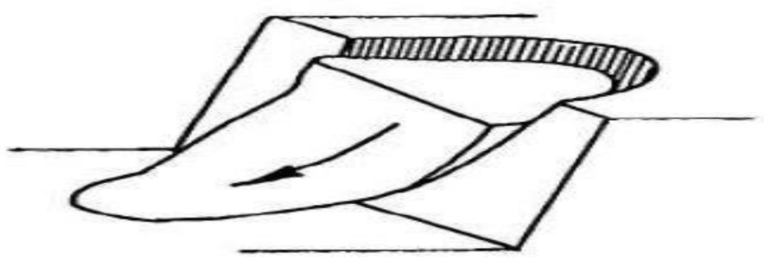


Fig. 2.9 Three-dimensional failure geometry of a rotational shear failure (after Hoek and Bray, 1981).

Types of circular failure

Depending upon the area that is being affected by the failure surface, the circular failure can be categorized into the following categories.

1. Slope failure
2. Base failure
3. Toe failure

2.5.4 TOPPLING FAILURE

This kind of the deterioration involves rotation of series of blocks or columns of rock about a permanent base are termed as toppling failure. For the first time Muller in 1968, proposed that rotation of block or toppling is a major factor in the failure of north face of Vaiont slide (Figure 2.10). Hofmann in 1972 under Muller, performed number of model studies to scrutinize block rotation. After Hofmann several model studies were carried out by Soto (1974), Ashby (1971) and Whyte (1973), while Cundall (1971), Byrne (1974) and Hammett (1974) who integrated rotational failure modes into computer analysis of rock mass behavior.

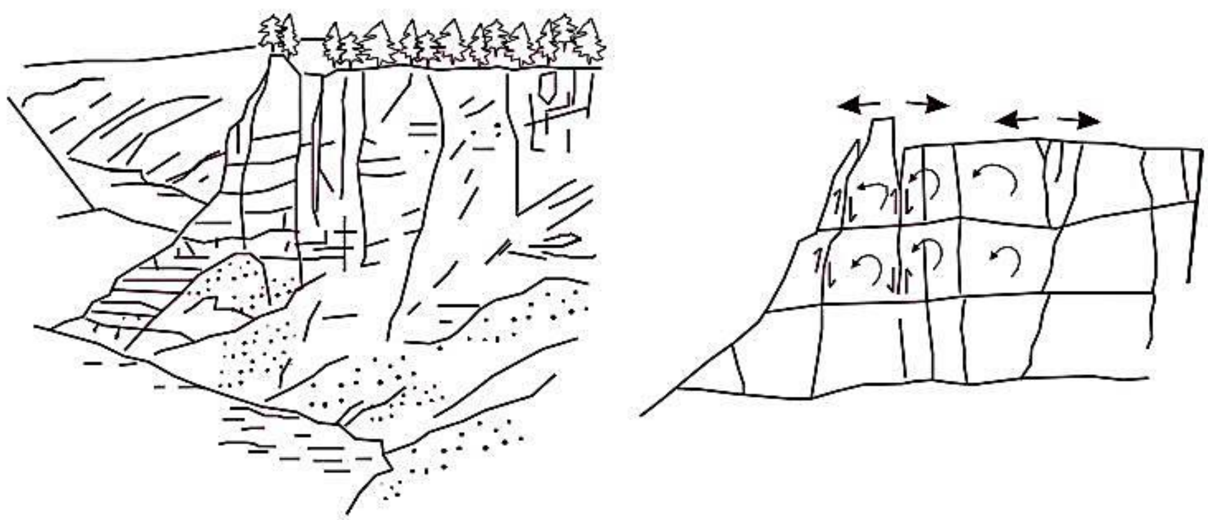


Fig. 2.10 Toppling mechanism of the north face of Vaiont slide (Muller, 1968)

At the point when the weight vector of block of rock resting on a slanted plane falls outside the base of the block, this prompts toppling failure. This kind of failure may happen in undercutting beds (Fig. 2.11). When they are bothered the framework may crumple or this failure has been proposed as the reason for a few failures going from little to substantial. This kind of failure by and large happened when the hill slopes are extremely steep.

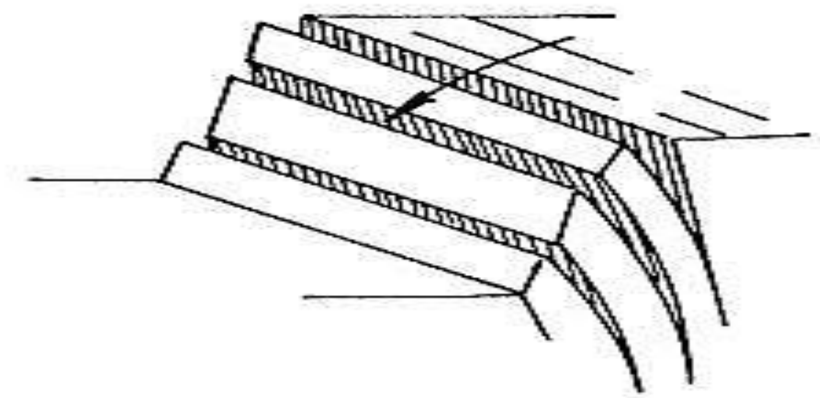


Fig. 2.11 Toppling Failure (modified after Hoek & Bray, 1981)

(Source: www.dipanalyst.com/Kinematic%20Analysis/Kinematic%20Analysis.html)

2.6 REASONS FOR SLOPE FAILURE IN MINES [9]

There are many reasons exist for a bench slope failure. Some of them are:

- Dynamic loading due to blasting, earthquake, and HEMM (heavy earth moving machineries) etc. shear stresses increases instantly in the rock mass as the result of vibration.
- Water pressure in the joint is also liable for frequent slope failure than all other causes taken together.
- Very often the location, orientation and properties of structural discontinuities in the rock mass acts as a major factor for rock slope failure.
- Due to lack of supervision in the high-wall bench.
- Flooding of floor due to existence of aquifers.
- Because of the decrease in the cohesion and friction angle value of dump materials.
- In deep-hole blasting maintenance of slope angle is also very difficult and probability of slope failure becomes very high.

2.7 FACTOR OF SAFETY (FOS)

This can be is defined as the ratio of the maximum force which resists sliding and the existing force which likely to cause sliding. The definition of factor of Safety (FOS) can be expressed as follows:

i. Maximum mobilitable shear strength / Effective mobilized shear stress

ii. H_c / H Critical Height /Slope Height

iii. Fr/F_d Resisting Force/ Driving Force

iv. s/τ Available Shear Stress /Shear Stress at Equilibrium

v. M_r / M_d Resisting Moment/Driving Moment

Table 2.1 Guidelines for Equilibrium of a Slope (www.wise-uranium.org/cssth.html)

Factor of Safety	Details of Slope
<1.0	Unsafe
1.0 – 1.25	Questionable safety
1.25 – 1.4	Satisfactory for routine cuts and fills, Questionable for dams, or where failure would be catastrophic
>1.4	Satisfactory for dams

CHAPTER - 3

PROJECT METHODOLOGY

CHAPTER - 3

PROJECT METHODOLOGY

3.1 METHODOLOGY FOR PROJECT

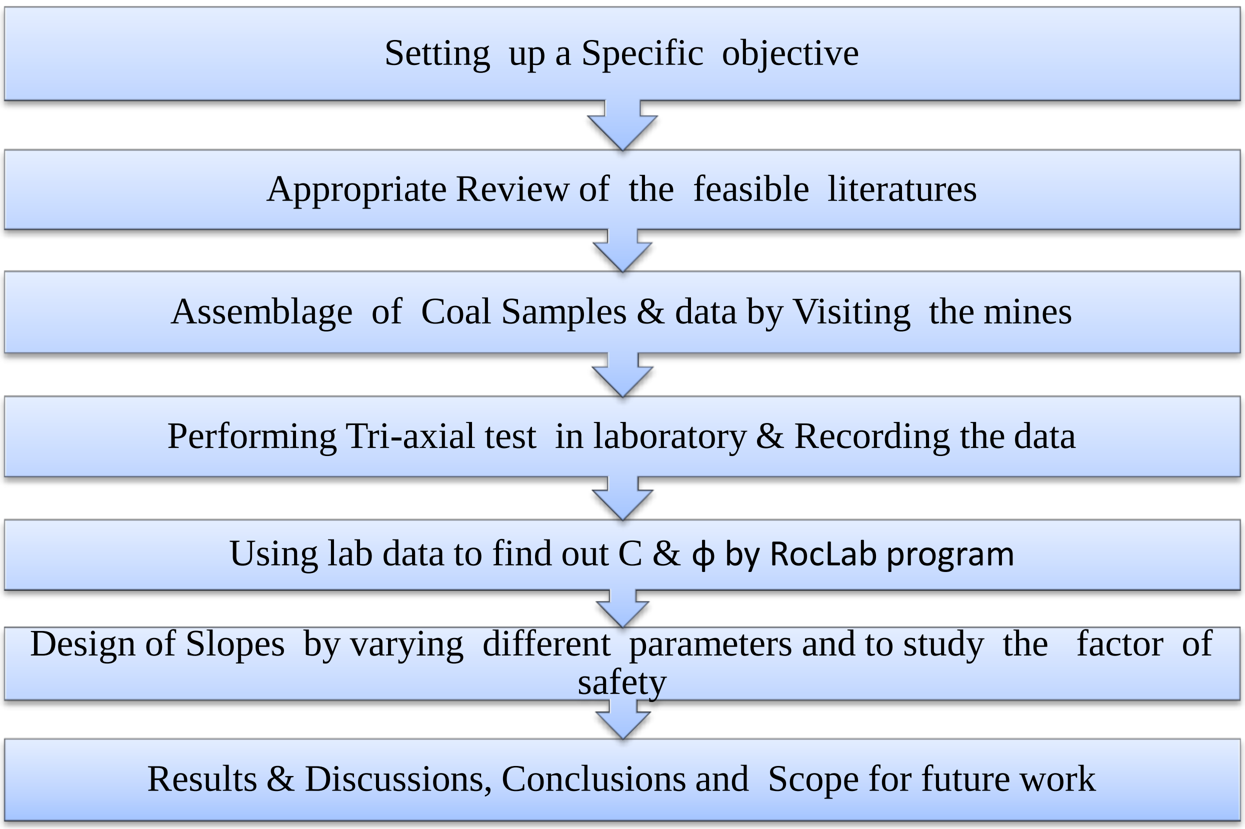


Fig. 3.1 Methodology of the research

3.2 RESEARCH STRATEGIES

- Many literatures were studied for understanding the various modes of failures in slope.
- Numerical modelling software OASYS & FLAC/Slope was reviewed for its utilization in evaluating the slope stability in the open pit mine.
- Field study was performed in the Samaleswari Opencast Mine having 50 m ultimate pit depth at Jharsuguda district in the state of Odisha.
- Laboratory analysis were performed on the rock samples collected during field study.

- Parametric studies were carried out by numerical models (FLAC/Slope & OASYS) to investigate consequences of cohesion (50-100kPa) & angle of internal friction (18^0-26^0 at the interval of 2°). Also the effect was studied by varying slope angle of the pit from 35° to 70° at an interval of 5°.

3.3 SLOPE STABILITY ANALYSIS AT SAMALESWARI OPENCAST PROJECT(SOCP): A CASE STUDY [18]

Original project of Samaleswari OCP was planned for 3 Mty capacities, which was sanctioned in August 1992. Subsequently, due to increase of coal demand from Ib-Valley Coalfield, the project was expanded to 4 Mty (Ph-I) and then 5 Mty (PH-II). Phase-III expansion to 7 Mty was approved in April 2007 annexing additional area. Phase-IV expansion of the project is proposed for incremental production of 5 Mty (Total of 12 Mty) to meet the increased demand of coal from the coalfield. It is proposed to annex about 0.61 sq.km. Area in the north of the approved OCP boundary and thereby the barrier between Howrah-Mumbai railway line.

Fig. 3.2 Overview of Samaleswari OCP

3.3.1 Location of the Mine

Samaleswari OCP is located to the west of Hingir Rampur colliery in Jharsuguda district in the state of Orissa. It is situated between latitudes 210 47' to 210 49' North and longitudes 83053' to 830 55' East as per survey of India.

Fig. 3.3 Samaleswari OCP in Odisha map (Source: Google image)

The present expansion project report has been prepared after appropriate additional area in the dip side up to the proposed OPGC railway line agreed by MCL.

Samaleswari OCP is well connected by road. A pucca all-weather road of about 2.5 km connects this mine to Brajrajnagar railway station situated in the west. It is approachable from Sambalpur via Jharsuguda by road. Sambalpur is located at a distance of about 70 km. Jharsuguda is the district head quarter and is situated about 20km away from Brajrajnagar.

The mine boundary of the present project is as follows:

East - Incrop of Lajkura seam

North - Boundary is arrived after leaving surface barrier of 100m from Howrah-Mumbai railway line.

South - Fault F4-F4 and F6-F6 , East - In crop of Lajkura seam

West - 115m barrier from proposed OPGC railway line

Fig. 3.4 Samaleswari OCP (Source: Wikimapia.org)

3.3.2 Mine Geology

Original assessment of the geology of the block in 1983 was based on 38 boreholes involving 7410.30m of drilling, in which Lajkura seam was intersected and dip side drilling was still under progress. On the basis of subsequent drilling, necessary modifications have also been incorporated. The drilling done in this area amounts to 10898.55mts in 70 boreholes, covering an area of 4.38 sq. kms (excluding the extended are). Out of these, 37 boreholes have been drilled up to Ib seam and the rest 33 boreholes are up to Lajkura seam. The borehole density is about 16 boreholes/sq.km, excluding the annexed area.

3.3.2.1 SURVEY

There is a difference of 23.42m through- out the area between reduced level determined by Railways and by Survey of India. Reduced levels determined with respect to Railway bench mark have been used in all the reports and colliery plans.

3.3.2.2 BEDDING ATTITUDE

The general strike of the coal seams is NNE-SSW with a westerly/north westerly dip. In the northern half of the area the strike is N15^0/20^{0}E – S15^0/20^{0}W, which swings gradually to N45^0/60^{0}E – S45^0/60^{0}W in southern part because of the basinal shape of the coalfield and also due to major faults.

The gradient of the seam is gently and ranges between 1 in 12 to 1 in 30 (generally around 1 in 19) and dips towards north – west.

3.3.2.3 FAULTS

Some total 6 numbers of faults varying in magnitude and direction have been interpreted in the area under considerations. The major fault F_5 – F_5 brings the Talchir in juxtaposition with seams.

Table 3.1 Details of the Fault

No.	Approximate extent and Location	Trend	Amount & direction of throw	Evidence
F_1-F_1	In between O/B-148,132,130 & 122 on the upthrow side & O/B-133,131 & 84 on down throw side	E-W & became north south-west towards west and south – western part of the block	10m southerly	Level difference of Lajkura seam On both sides of fault.
F_2 –F_2	In between O/B-201,145,106 & 80 on upthrow side & O/B-139,138,108 & 82 on down throw side	E - W	2-10m Southerly	Level difference of Lajkura seam on both sides of the fault
F3-F3	In between O/B-151,131 & 59 on upthrow side & O/B- 149,188,152 & 119 on downthrown side	NW - SE	3m – 10m southerly	Level difference of Lajkura seam on both sides of the fault
F_4- F_4	In between O/B- 129 & 76 on upthrow side & O/B- 189,153 & 150 on downthrown side	NW - SE	18m – 20m northerly	Level difference of Lajkura seam on both sides of the fault
F_5 – F_5	In between O/B- 86,120 & 156 upthrow side & O/B- 153 & 129 on downthrown side	E - W	30m approx. northerly	Lajkura horizon completely missing in the upthrow side boreholes (i.e. O/B- 86,120 & 156)
F_6 -F_6	Further south of F_5 – F_5	E-W	Northerly throw to be proved	

3.3.2.4 COAL SEAM DESCRIPTION

Lajkura coal seam is presently being mined by open cast method in Samaleswari OCP whose capacity is decided to increase from 7Mty to 12 Mty. The total stratigraphical thickness of Lajkura horizon varies from 16.71 (O/B-145) to (O/B-192) Rampur colliery block. The seam is interbanded with coal, shaly coal, carb-shale, and shale. Parting between Lajkura horizon and Rampur horizon, is about 90m and consists of coarse-grained and granular sandstone. The effective thickness of the seam varies from 9.41m (O/B-133) to 25.49m (O/B-166), the average being 17 to 18m. Lajkura coal horizon has been intersected fully and /or partially in all the boreholes drilled in block under consideration. There is some deterioration towards the bottom portion of Lajkura seam in the south-western part of the block (O/B-131, 132, 133 & 138).

Lajkura seam splits into two sections, namely Lajkura Top and Lajkura bottom, separated by a parting of carb-shale/shale ranging from 1.00m (O/B-111) to 4.97m (O/B-133). In some boreholes (O/B-82, 99,101, 108, 114, 130, 139, 151 & 196) the two sections are combined.

3.3.2.5 WORKING PLAN OF SOCP

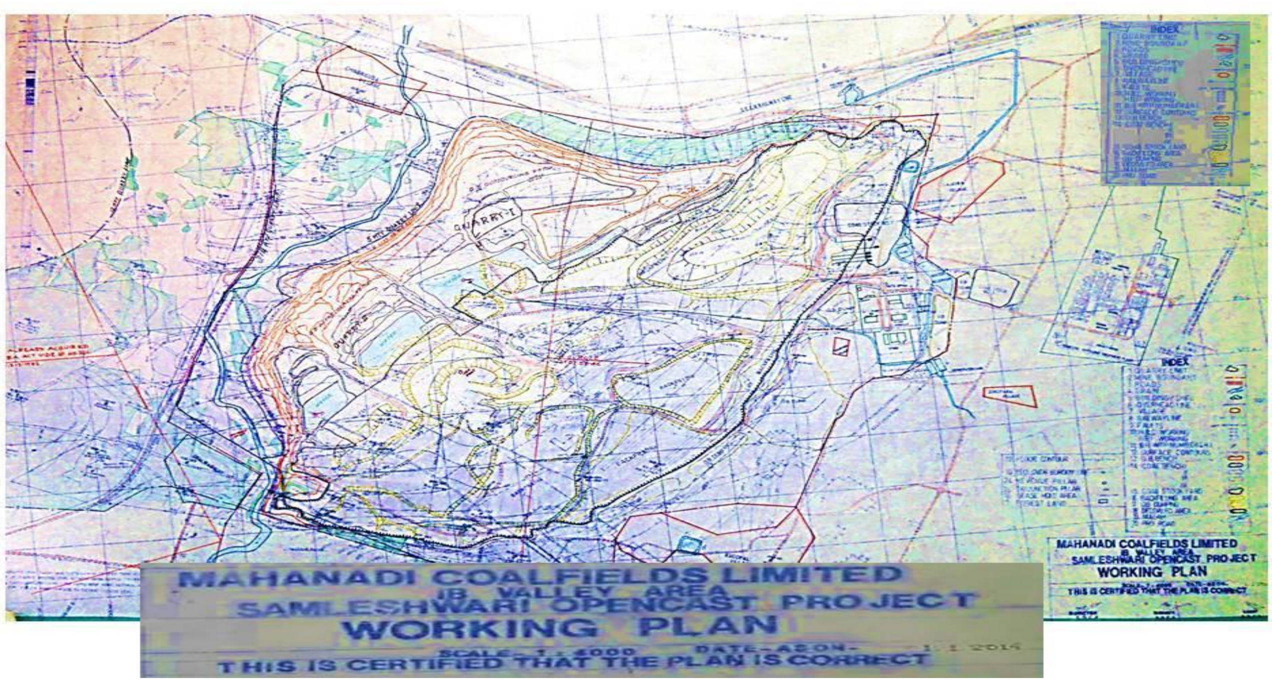


Fig. 3.5 Working Plan of Samaleswari OCP, IB Valley Area, Mahanadi Coal field limited

3.3.2.6 BOREHOLE SECTIONS

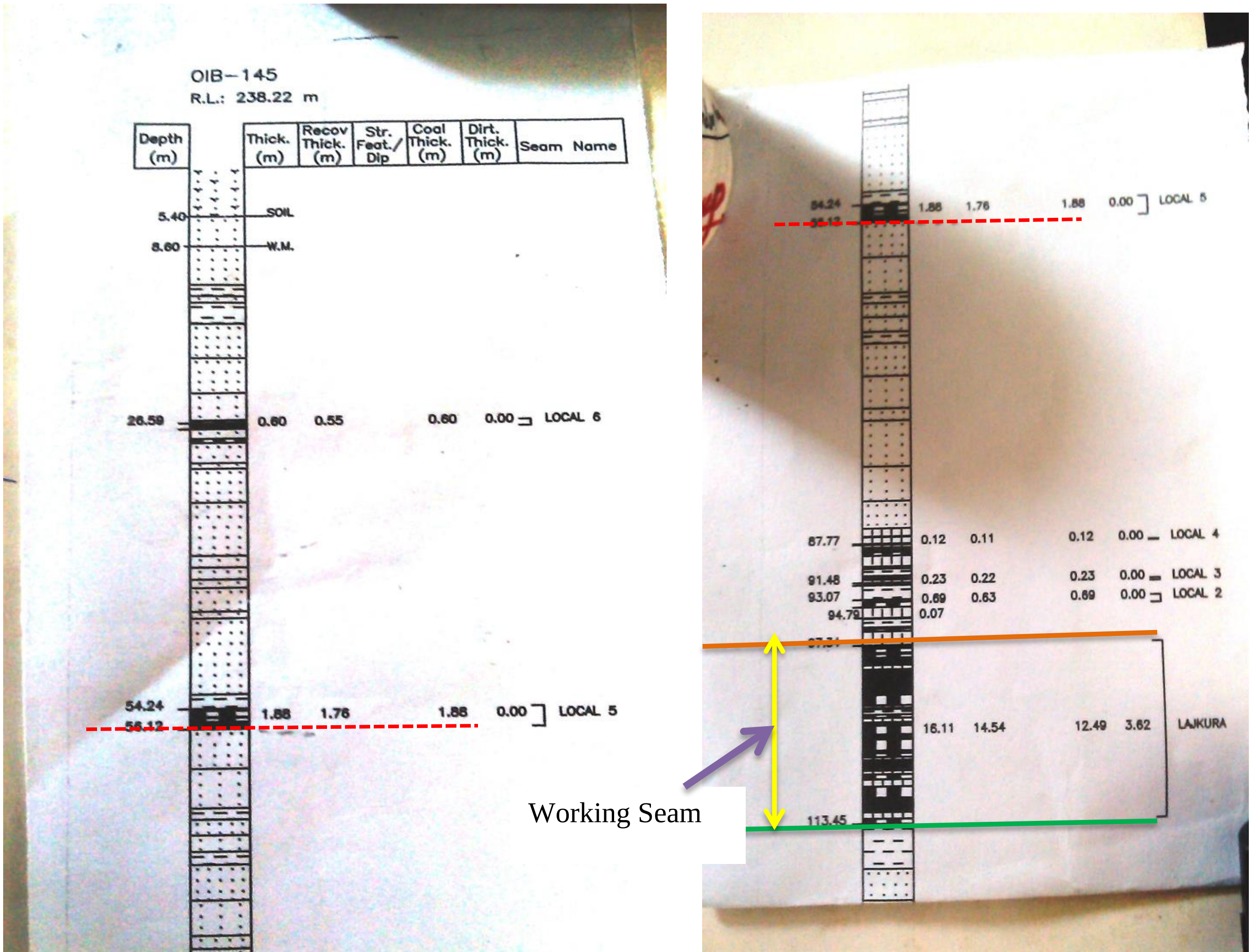


Fig. 3.6 Borehole Sections & Working Seam

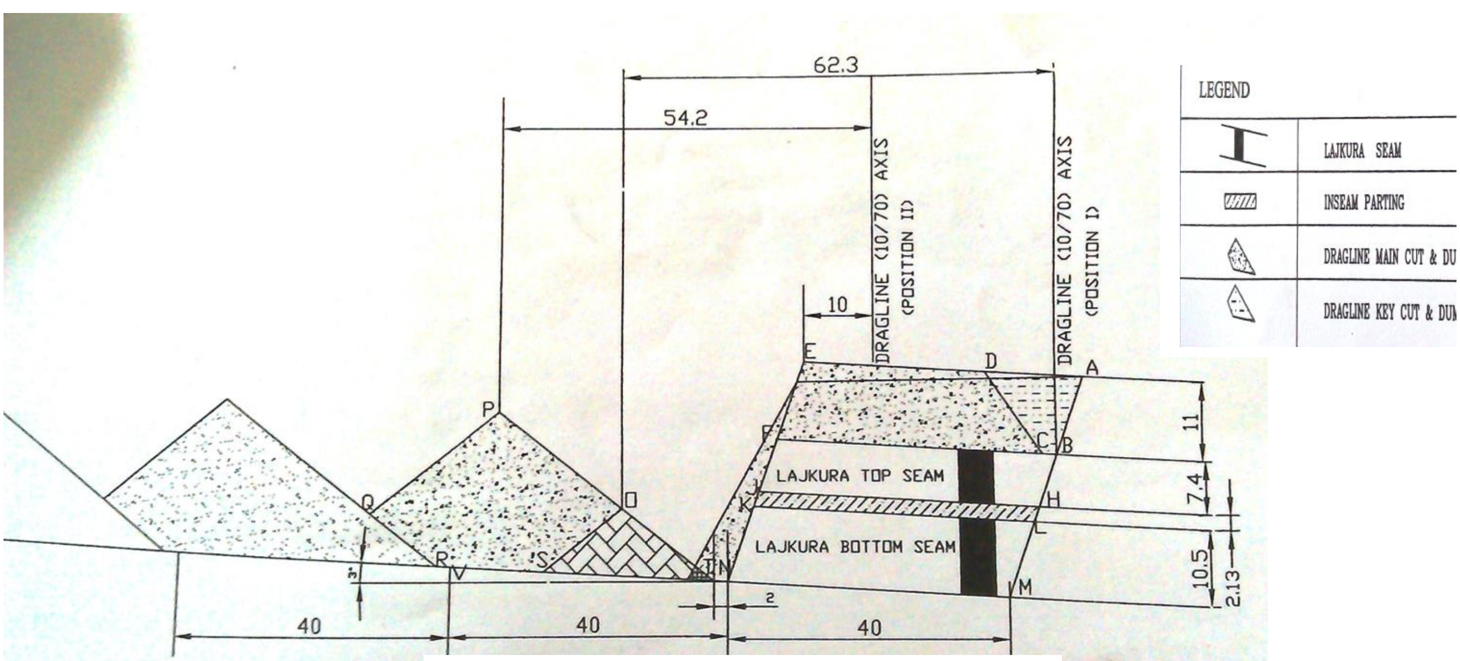


Fig. 3.7 Dragline Balancing Diagram

3.4 MAJOR MACHINERY USED

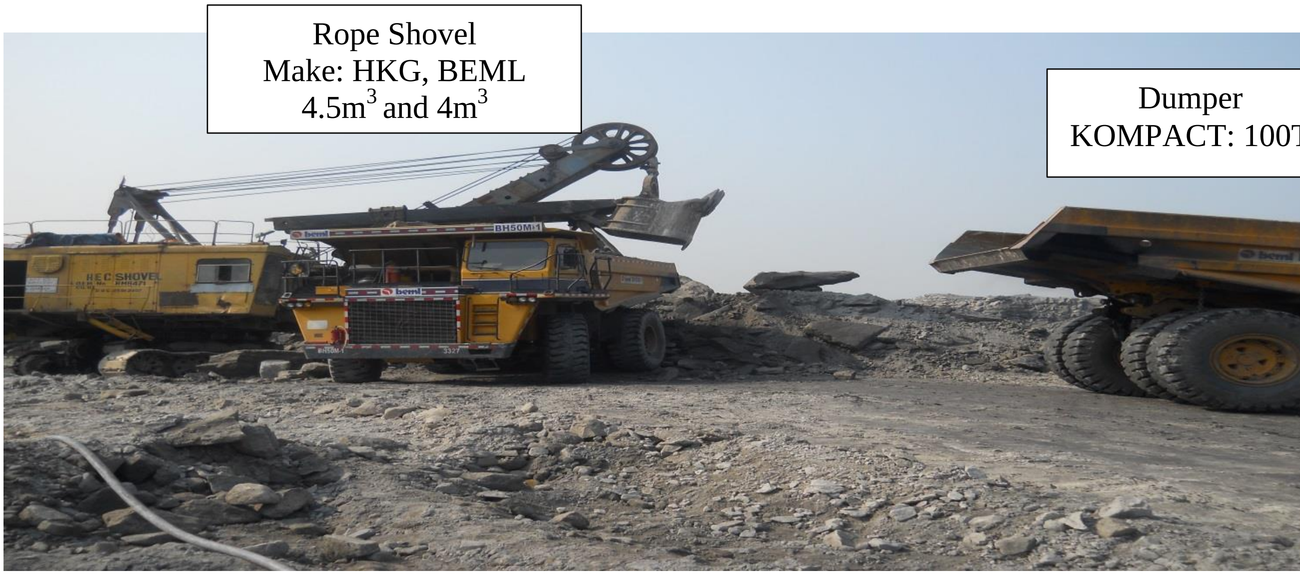


Fig. 3.8 Major Machineries used at Samaleswari OCP

3.5 FIELD VISIT & DATA COLLECTION

The primary aim involves designing stable slopes so as to facilitate different operations safely. The two mechanical parameters which are required for this research are angle of internal friction and cohesion. Both parameters present engineering properties of the area which is under consideration.

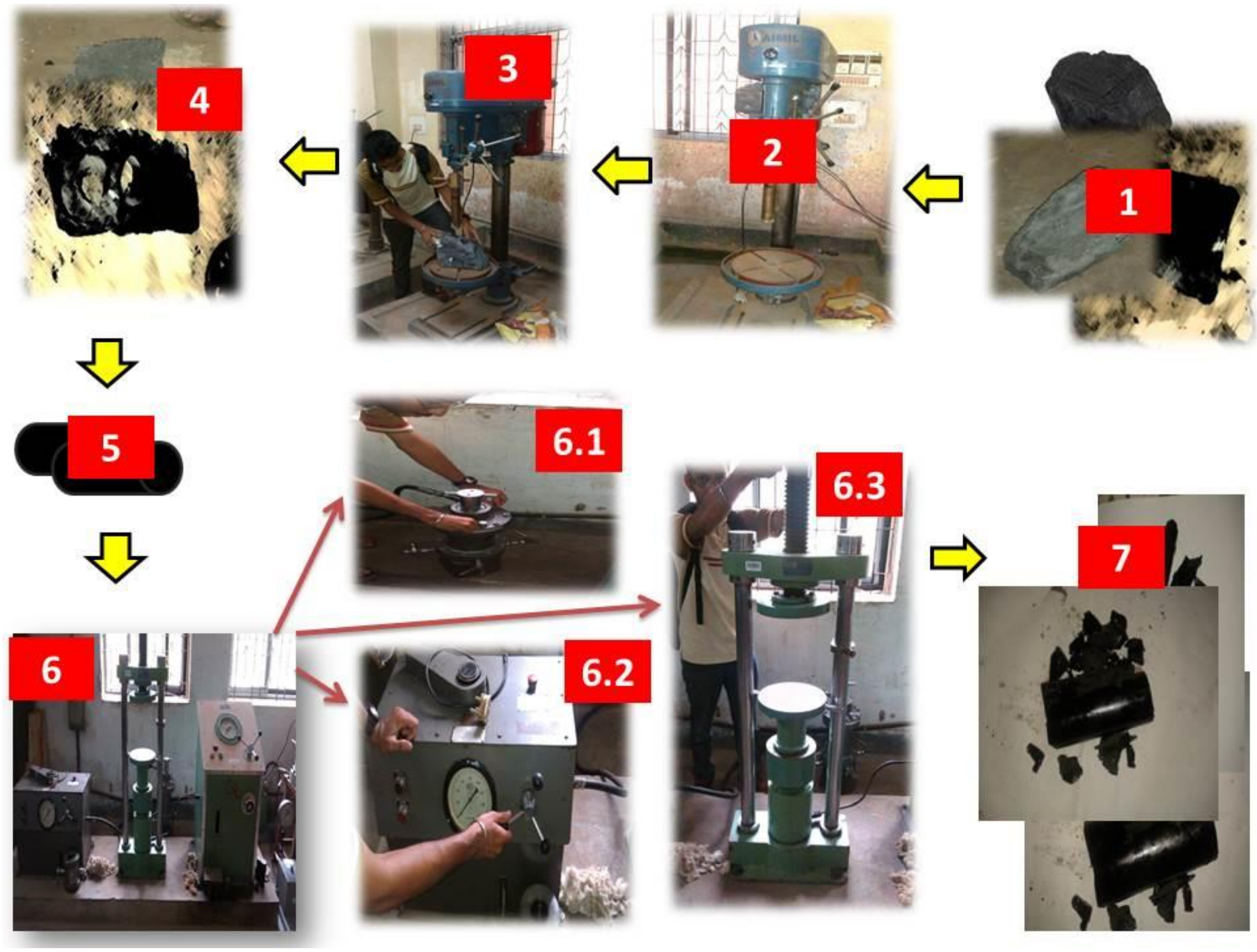


Fig. 3.9 Different steps carried out for testing the sample

1- Collection of coal lump from field

2- Coring machine

3- Coal lump on base of Coring machine

4- Coal lump after Coring

5- Coal samples prepared

6- Tri-axial machine

6.1- Tri-axial cell

6.2- Loading ram

6.3- Loading frame

7- Coal samples after test

3.6 LABORATORY TRIAXIAL TEST FOR DETERMINIG C & ϕ

It involves two operations:

a. Sample preparation
b. Tri-axial testing

3.6.1 Sample Preparation

After coring, three rock samples are cut into desired dimensions i.e. L/D >2, for the test.

The dimensions of the tested samples are listed below:

Table.3.2 Dimensions of the Coal samples

Sl.no.	L (in cm)	D (in cm)	L/D ratio
1	12	4	(12/4) = 3 > 2
2	11.9	4	(11.9/4) = 2.975 >2
3	11.5	4	(11.5/4) = 2.875 >2

3.6.2 Tri-Axial Testing

This test is one of the most widely used test for determine the strength as well as mechanical properties (i.e. stress- strain properties) of many deformable solids.

3.6.3 Types of tri-axial test

- Consolidated drained
- Consolidated undrained
- Unconsolidated undrained

3.6.4 Description of the apparatus

The apparatus used in the testing of rock samples with a cell that is so designed to indulge a pressure of 150kgf/cm^2 laterally and can be used in AIM-050, load frame 500kN of capacity. By using AIM-246 lateral pressure can be applied, with constant pressure system i.e. 150kgf/cm^2.

3.6.5 Construction of the apparatus

The following are the different parts of the equipment: It is made up of a base that occupies four valves used for measuring top drainage, pore pressure etc. in addition to that a center hole is provided at base for fixing the location pin & pedestal present at bottom in to various sizes as per requirement.

Besides that the apparatus is provided with ten threaded holes & two more locating pins which serve for clamping and aligning the chamber. The chamber is made with two handles acts for the purpose of lifting and ten free holes. Two plugs namely air plug and pressure inlet plug is provided with the top cap which is a permanent arrangement with the chamber. A plunger is provided which can be raised with two pins on the top of the plunger.

Fig. 3.10 Tri-axial test apparatus

3.6.6 Criteria to be satisfied by the Test Specimen

- The largest particle encompass within test specimen should be less than one sixth of the specimen diameter.
- The L/D = should be in between 2 &3 measured to nearest 0.3mm.
- The cross section of the specimen should be uniformly circular with the ends perpendicular to the axis of the specimen.
- The specimen should be carefully handled in order to mitigate change in cross section, loss of moisture content & to keep away the disturbances.

3.6.7 Test Procedure

- The chamber is removed and cleaned by Allen keys.
- Also base is cleaned and a fine layer of the oil is place on it.
- The chamber is filled with oil & the sample is kept within, pedestal & a loading pad of same size is placed on the top of sample. Then the chamber is to kept in the locating pin and clamped to base by Allen bolts provided.
- A load of 0.2MPa is kept on the constant pressure system.
- Then by up-down the handle of system same load is transmitted to the oil filled chamber. Which are acts as the '$\sigma 3$' for sample under testing.
- When a load of same quantity is developed in the system, then load is applied from the loading ram until there is no further advance in the needle of the ram.
- No further advancement in the needle implies that the sample has been broken.
- Then the reading is noted, which gives "σ_1" for the sample.
- The same procedure is applied for load of 0.4MPa & 0.6MPa.
- The readings were tabulated.

- ❖ Now those reading can be put into the RocLab software for determining cohesion and angle of internal friction, which is the aim of this test.

3.6.8 Data obtained from the test

Table 3.3 Reading from the Tri-axial test

Sample no.	σ 1(in MPa)	σ 3(in MPa)
1	2.7	0.2
2	3.2	0.4
3	3.8	0.6

3.6.9 Mohr's Circle obtained from the RocLab Program

From the reading obtained from the test a Mohr-Circle is plotted to find out the cohesion & angle of internal friction of the samples:

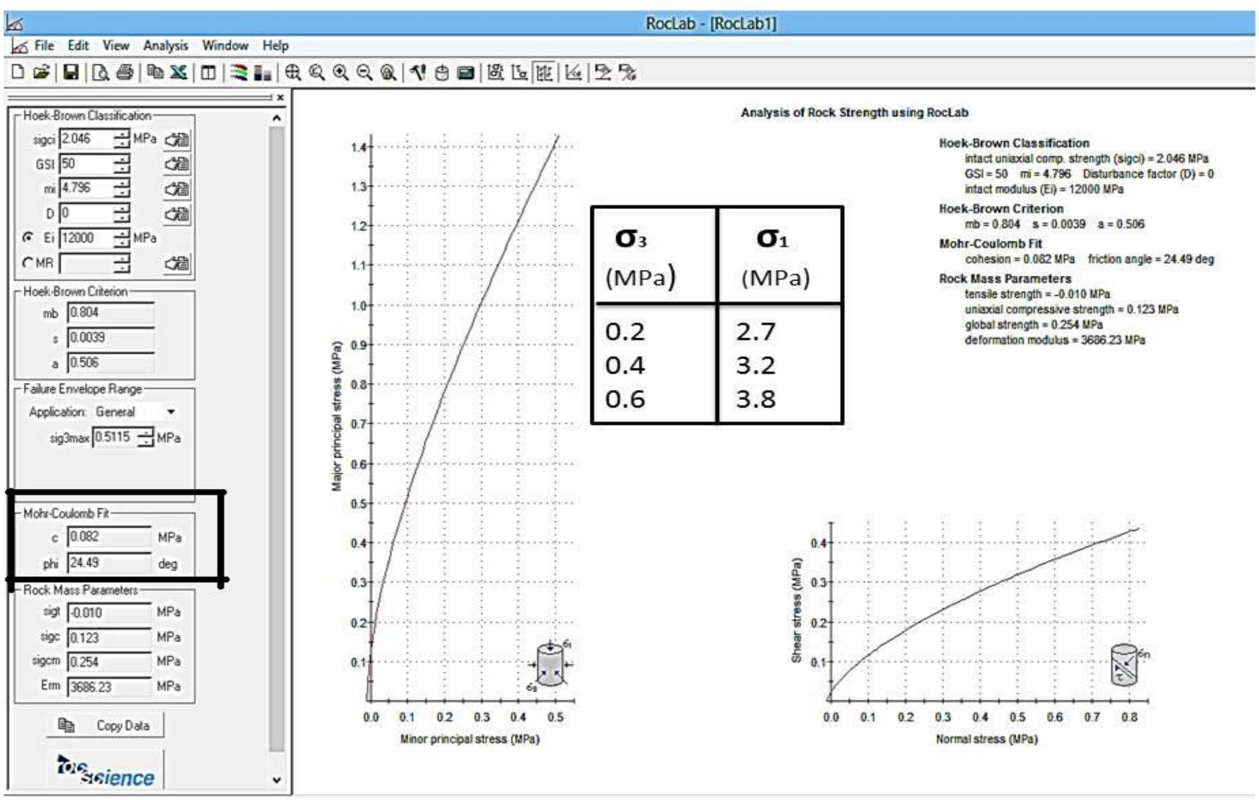


Fig. 3.11 Mohr- circle for finding out of cohesion and angle of internal friction

3.6.10 Results of Tri-axial test

From the test cohesion and angle of internal friction are found to be:

Table.3.4 Test results for c and ϕ

Cohesion(in MPa)	Angle of internal friction (in degree)
0.082	24.49

3.7 NUMERICAL MODELLING USING FLAC SLOPE & OASYS

Introduction

In general most of the slope instability related with complexities associated to material anisotropy, non-linear behavior, geometry, in situ stresses and the presence of several coupled processes (e.g. pore pressures, seismic loading, etc.). Numerical modelling method is an appropriate method for those problems which cannot be determined by conventional methods. Numerical methods can be further divided into three main sub-categories: discontinuum, continuum and hybrid modelling.

3.7.1 Reasons for doing Numerical Modelling

i. Numerical analysis can help to explain observed physical behavior.
ii. Numerical analysis can evaluate multiple possibilities of geological models, failure modes and design options.
iii. Numerical analysis can incorporate key geologic features such as faults and ground water providing more realistic approximations of behavior of real slopes than analytic models.

3.7.2 Numerical Analysis Method Vs Limit Equilibrium Analysis Methods

Table 3.5 Comparison of numerical and limit equilibrium analysis methods (Source: Wyllie & Mah, 2004)

Analysis result	Numerical solution	Limit equilibrium
Equilibrium	Satisfied everywhere	Satisfied only for specific objects, such as slices
Stresses	Computed everywhere using field Equations	Computed approximately on certain surfaces
Deformation	Part of the solution	Not considered
Failure	Yield condition satisfied everywhere ;slide surfaces develop “automatically” as conditions dictate	Failure allowed only on certain pre-defined surfaces; no check on yield condition elsewhere
Kinematics	The “mechanisms” that develop satisfy kinematic constraints	A single kinematic condition is specified according to the particular geologic conditions

3.7.3 Different programs available for stability analysis are as follows

- FLAC SLOPE
- GALENA
- OASYS
- ROCFALL
- UDEC
- SLIDE
- SLOPE/W
- CLARA-W
- DIPS
- PFC2D/3D
- SVOFFICE
- GEO-STUDIO

- FLAC 3D
- ELFEN
- 3DEC

3.8 GENERAL APPROACH OF FLAC

The designing of geo-engineering methods includes unique examination and formulated ideas, different from that pursue for design with manufactured materials. The numerical "sample" must be prepared carefully, and several samples tested, to gain an understanding of the problem. Table 3.6 lists the steps recommended to perform a successful numerical experiment.

Table 3.6 Recommended steps for numerical analysis in Geomechanics (User's Guide, 2002)

Step I	Defining the aim of the model analysis
Step II	Conceptual picture of the physical system is created
Step III	Simple idealized models are created & run
Step IV	Problem-specific data are put together
Step V	A series of detailed model runs are prepared
Step VI	Model calculations are carry out
Step VII	Thus the result obtained is interpreted

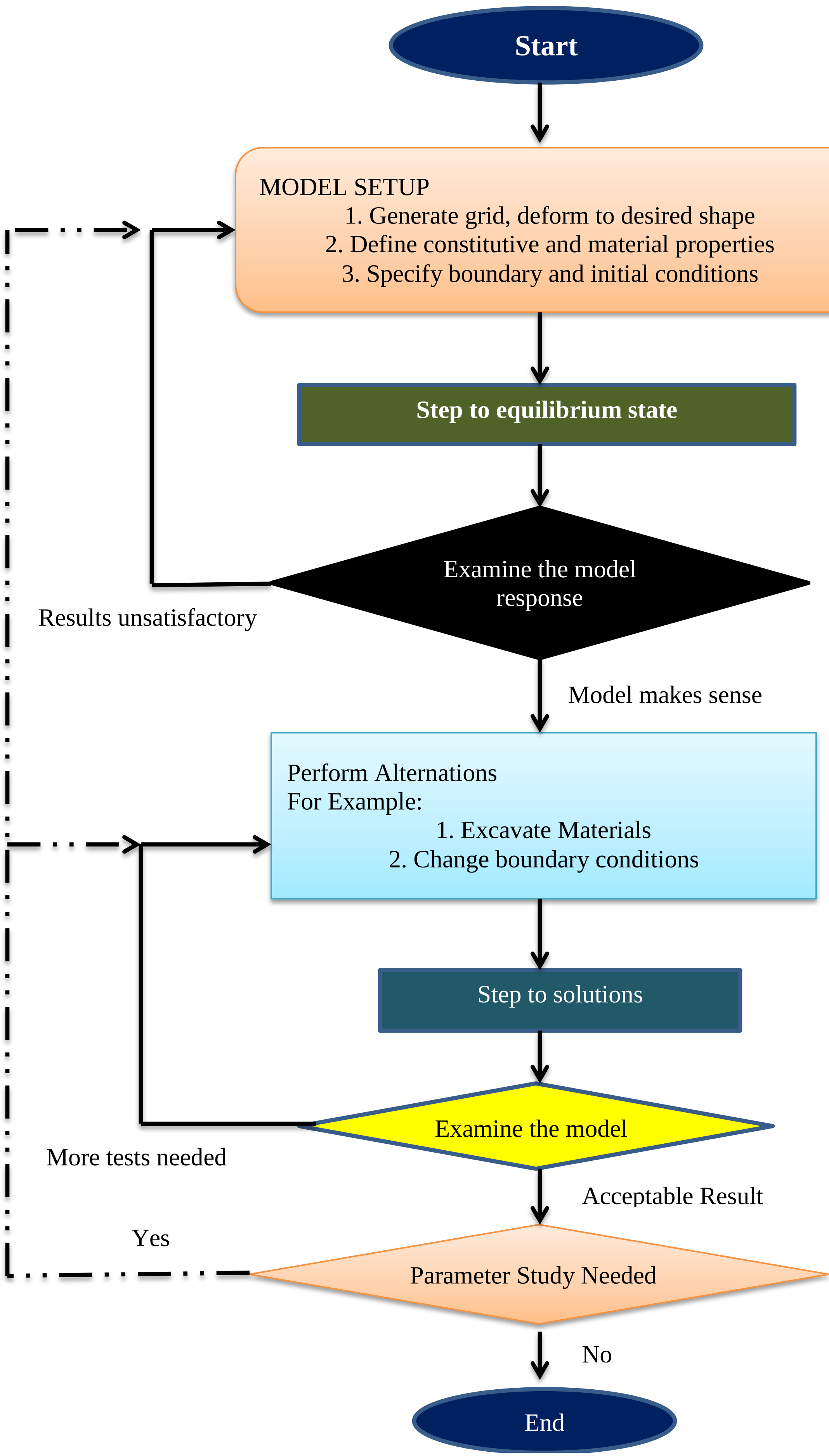


Fig. 3.12 Flow chart for determination of factor of safety using FLAC/Slope (User's Guide, 2002)

3.9 FLAC /SLOPE (Fast Lagrangian Analysis of Continua) [12] [15]

3.9.1 Overview (FLAC/Slope User's Guide, 2002)

FLAC/Slope is a mini-version of FLAC that is arranged particularly to do factor of safety counts for slope-stability examination. This version is executed only from FLAC's graphical interface (the GIIC) which help for quick genesis of models for rock slopes/ or soils & description of their circumstances identified with stability.

FLAC/Slope actualizes conventional "limit equilibrium" projects to choose factor of safety's. Limit equilibrium codes utilize an unpleasant procedure — typically focused around method of slices — in which different number of speculation are made (for e.g., angle & area of interslice forces). FLAC/Slope doesn't take longer time to choose factor of safety than a limit equilibrium program.

3.9.2 Procedure for Analysis

FLAC/Slope is particularly designed to operate numerous analysis and studies based on different parameters for stability of slope program. The structure of the program facilitate designing of numerous models in a project to be efficiently constructed, stored and can be accessed for comparing of model results straightforward. A FLAC/Slope analysis is commonly consists into four stages, they are:

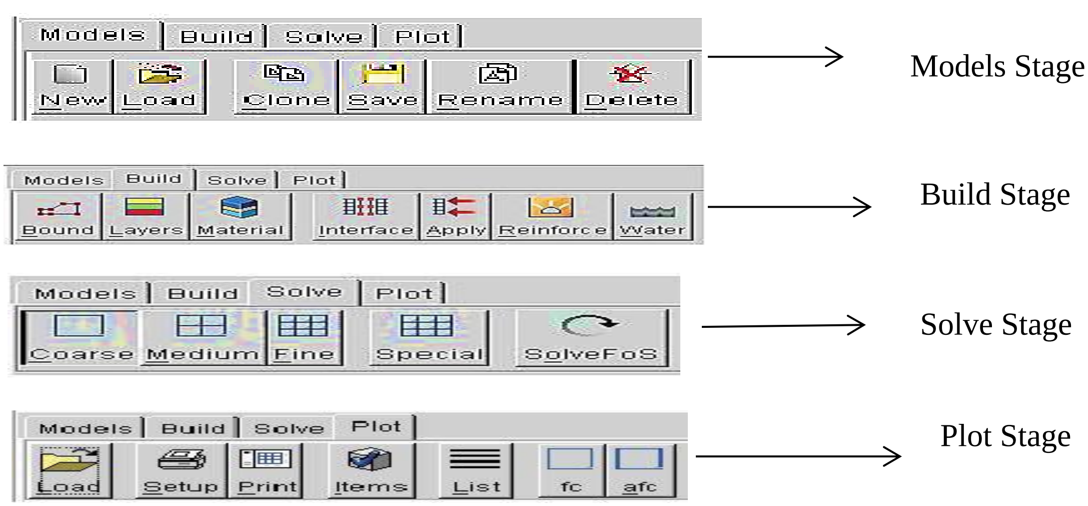


Fig. 3.13 Modeling-stage tool bars for each stage (User's Guide, 2002)

3.10 OASYS (Slope19.0_manual.pdf) [20]

3.10.1 Program Description

Slope has been essentially designed to inspect the slope stability, with an option to incorporate soil reinforcement. It can also be used to study earth pressure and problems related to bearing capacity. The program can examine both circular and non-circular failures, thereby enabling calculations to be carried out for soil & rock slopes.

3.10.2 Features of the Program

The core features of Slope are listed below:

- **Slope** specifies the following methods of analysis:

- ❖ Bishop's methods
- ❖ Janbu's methods
- ❖ Swedish circle (Fellenius) method

3.10.3 Procedure for Finding out the Factor of Safety

SL no.	Operations
1	From the Start menu the program is opened
2	On the Start-up screen select the option to "Create a new data file".
3	General file information is added.
4	Select the required Units for data entry and presentation of the calculations via the Data | Units option from the program menu or via the gateway.
5	Select the type of analysis, direction and type of slip via General Parameters.
6	The analysis method and related data are selected
7	The material is defined along with their properties.

8	Strata are defined & material is assigned to each stratum.
9	Slip surface data is defined & also centre/grid and the radius for circular slips defined.
10	The data is analyzed& a warning/ error messages are shown if the data are inappropriate.
11	After analysis the Print Selection Dialog will be displayed if analysis is successful. Click OK to see the Tabular Output.
12	The Graphical Output View gives a graphical representation of the strata, slips and grid centers and their results.

3.10.4 Components of the User Interface

The major components of Slopes' user interface are the Gateway, Table Views, Graphical Output, Tabular Output, toolbars, menus and input dialogs.

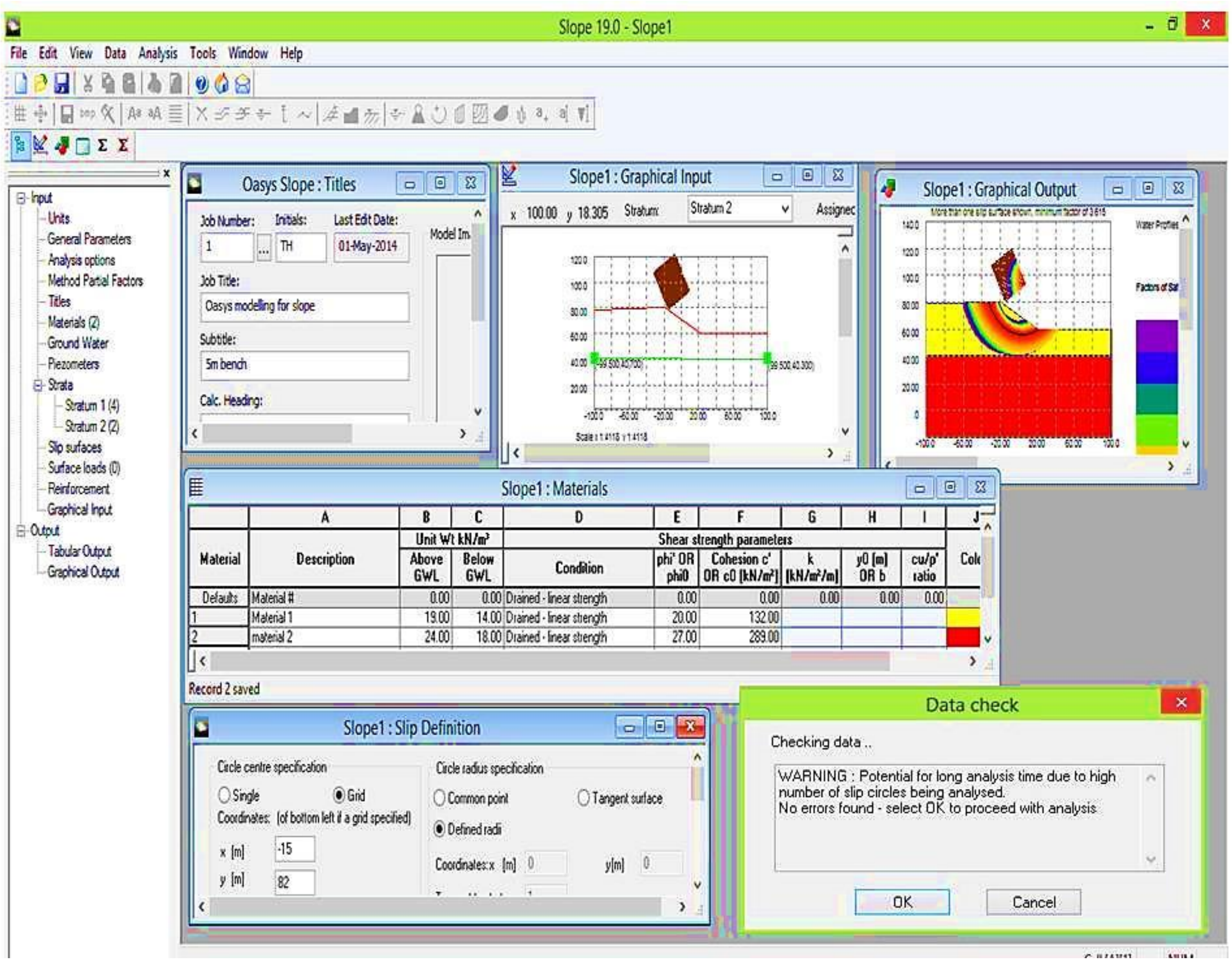


Fig. 3.14 Components of user interface of OASYS

3.11 PARAMETRIC STUDIES

Parametric studies were performed via numerical models (OASYS & FLAC/Slope) to investigate the variation of the angle of internal friction (18°-26° at an interval of 2°) & Cohesion (50-100kPa at an interval of 10kPa) on FOS. Also, Pit slope angle was varied from 35° to 70° at an interval of 5°.

Table.3.7 Factor of safety for various slope angles (Depth= 110m)

Sl.no.	**Slope Angle (in degree)**	**Angle of internal friction (in degree)**	**Cohesion (in kPa)**	**Factor of safety**	
				FLAC/Slope	**OASYS**
1	35	24	82	5.37	5.43
2	40	24	82	5.34	5.35
3	45	24	82	4.86	5.13
4	50	24	82	4.75	5.00
5	55	24	82	4.47	4.70
6	60	24	82	4.44	4.70
7	70	24	82	4.34	4.37

Several models were developed by OASYS & FLAC/Slope with varying Cohesion and angle of internal friction:

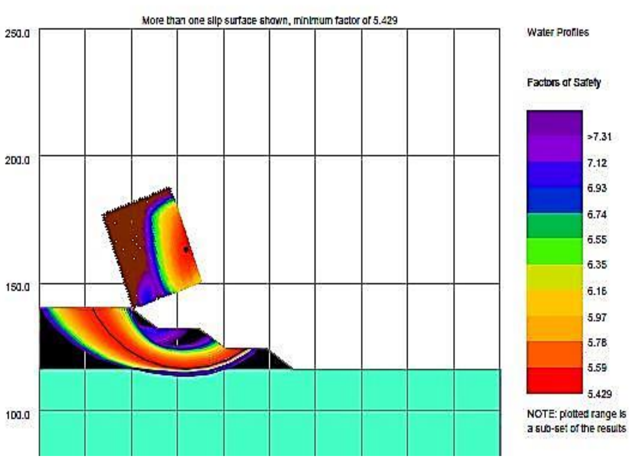
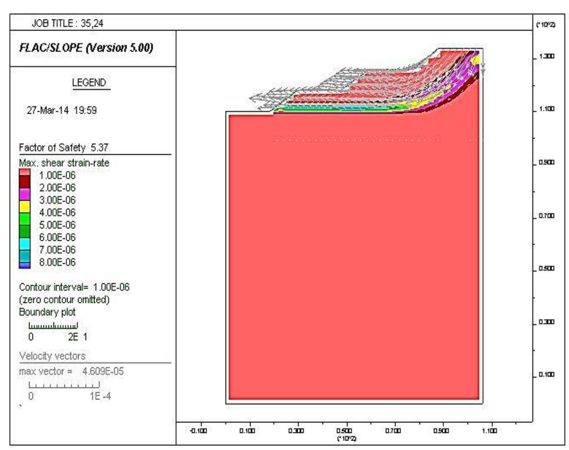
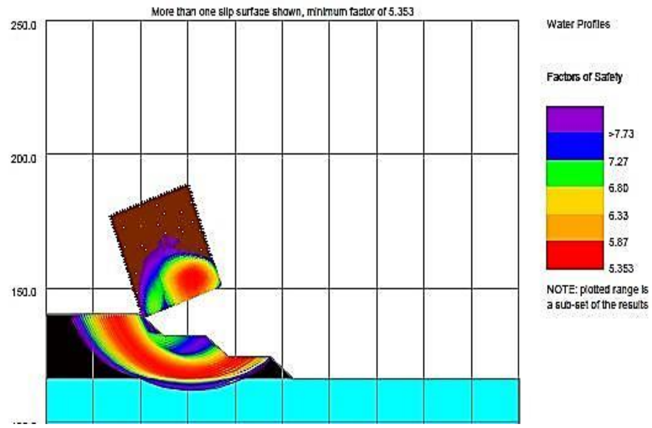
OASYS	**FLAC /Slope**
FOS: 5.43 	FOS: 5.37 

Fig.3.15 Model with Depth = 110m, Slope angle = 35^0, Angle of internal friction = 24^0

FOS = 5.35

FOS = 5.34



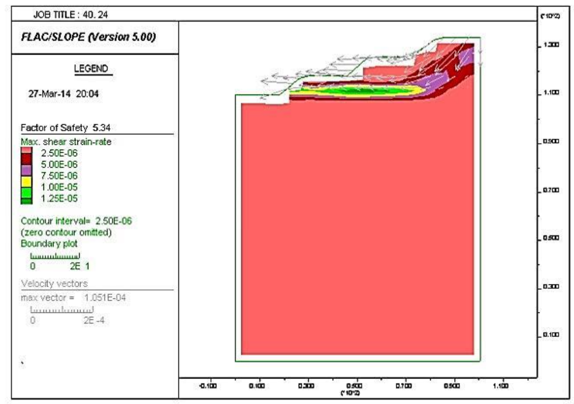
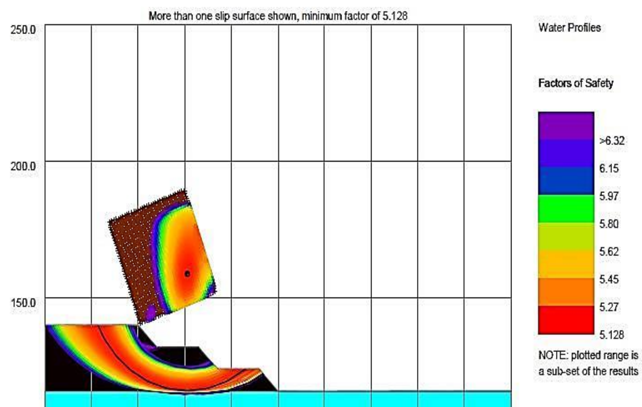


Fig.3.16 Model with Depth = 110m, Slope angle = 40^0, Angle of internal friction = 24^0

FOS = 5.13

FOS = 4.86



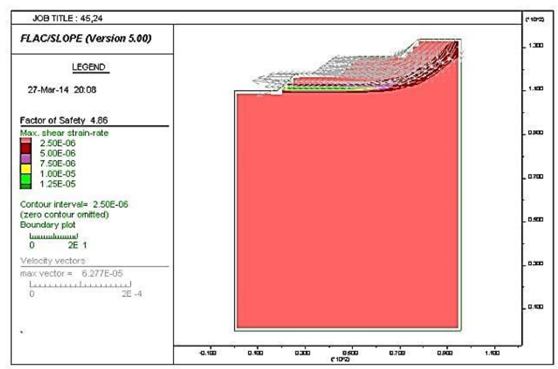
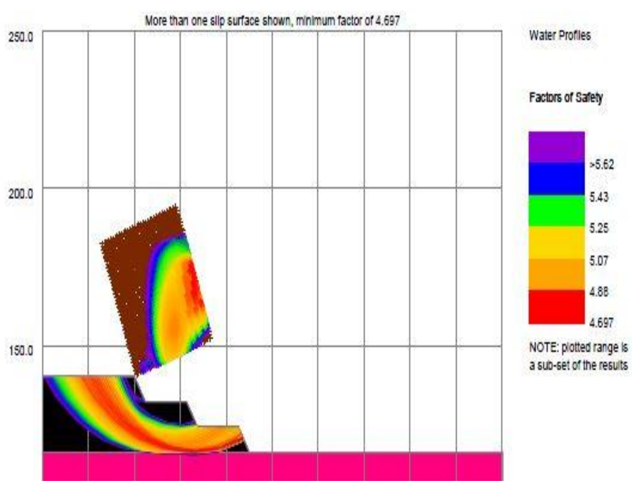


Fig.3.17 Model with Depth = 110m, Slope angle = 45^0, Angle of internal friction = 24^0

FOS = 4.70

FOS = 4.44



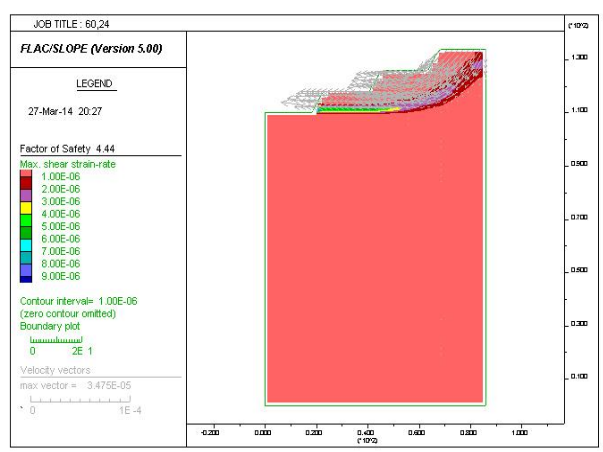
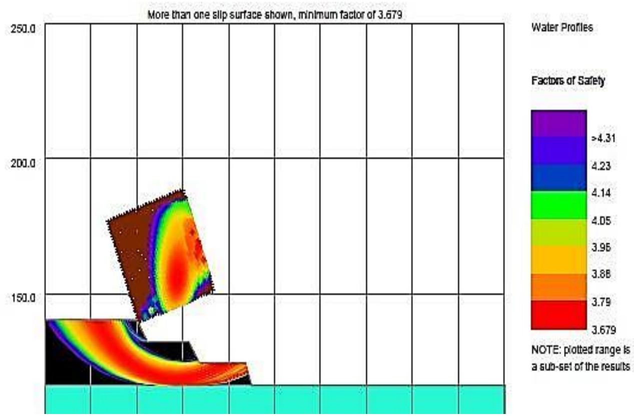


Fig.3.18 Model with Depth = 110m, Slope angle = 60^0, Angle of internal friction = 24^0

FOS = 3.70



FOS = 3.38

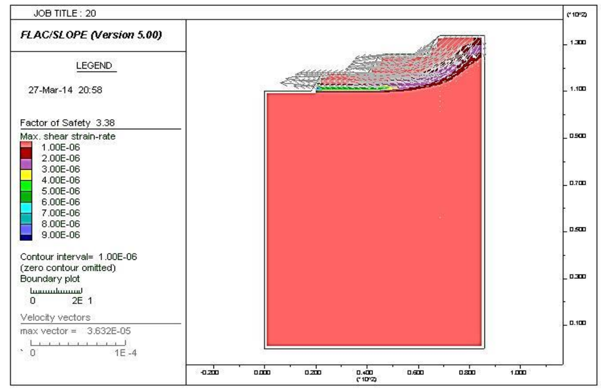
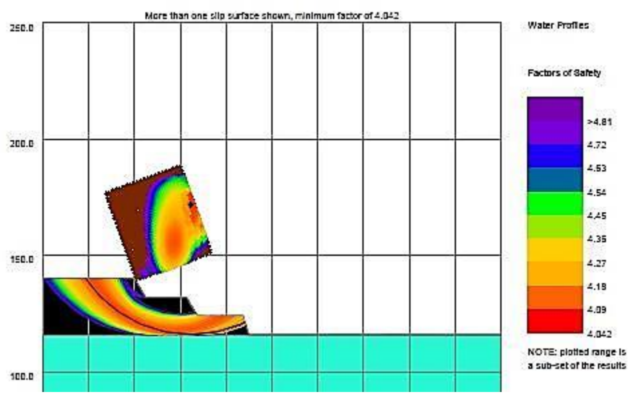


Fig.3.19 Model with Depth = 110m, Cohesion = 60kPa, Angle of internal friction = 20^0

FOS = 4.04



FOS = 3.72

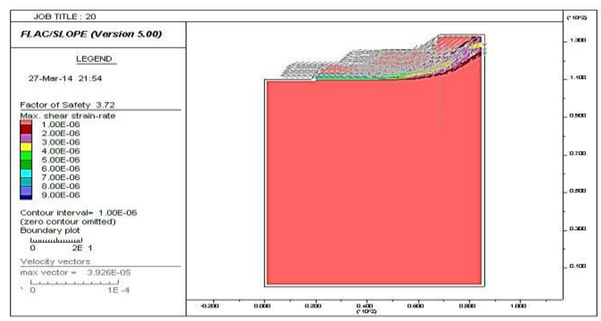
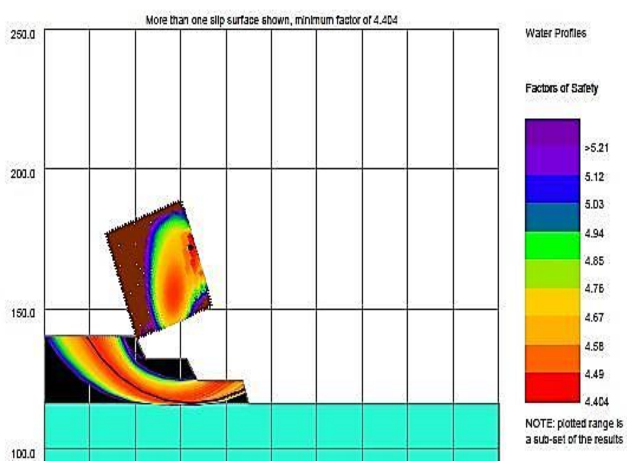


Fig.3.20 Model with Depth = 110m, Cohesion = 70kPa, Angle of internal friction = 20^0

FOS = 4.40



FOS = 4.07

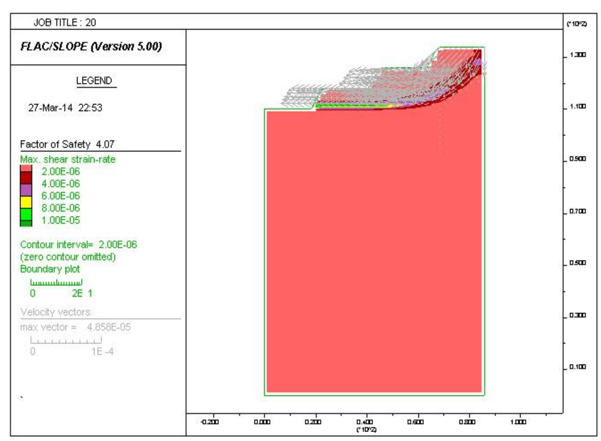
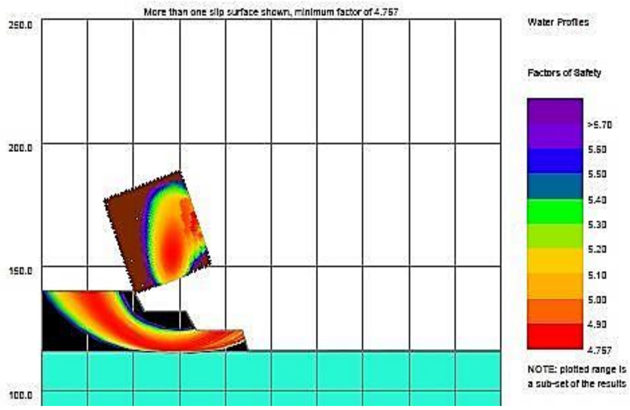


Fig.3.21 Model with Depth = 110m, Cohesion = 80kPa, Angle of internal friction = 20^0

FOS = 4.77



FOS = 4.41

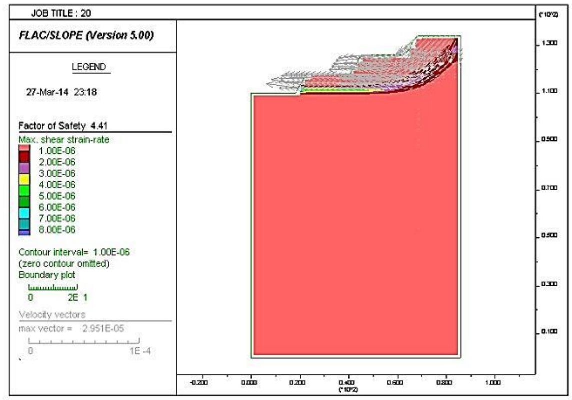
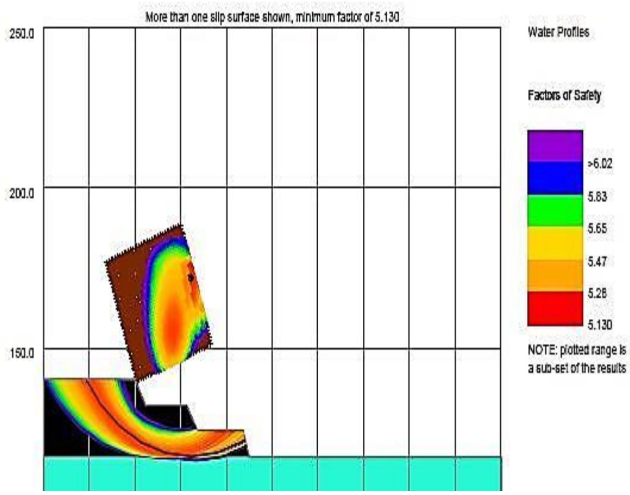


Fig.3.22 Model with Depth = 110m, Cohesion = 90kPa, Angle of internal friction = 20^0

FOS = 5.13



FOS = 4.75

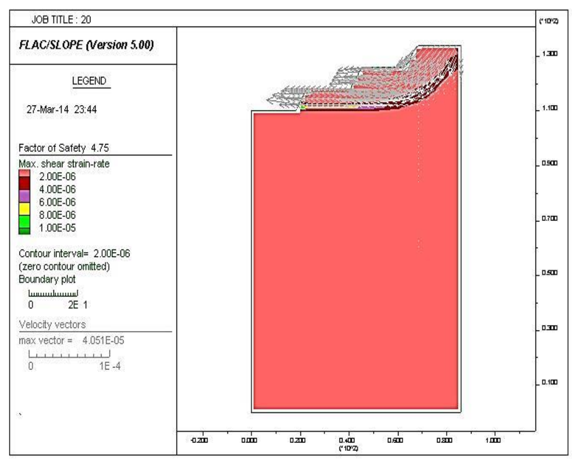


Fig.3.23 Model with Depth = 110m, Cohesion = 100kPa, Angle of internal friction = 20^0

Table.3.8 Factor of safety for various Cohesion and Angle of internal friction (Depth = 110m)

Sl.no.	Cohesion (in kPa)	Angle of internal friction (in degree' ^{0}')	Factor of safety	
			FLAC SLOPE	OASYS
1	50	18	2.90	3.16
		20	3.02	3.31
		22	3.16	3.47
		24	3.30	3.54
		26	3.46	3.61
2	60	18	3.23	3.16
		20	3.38	3.68
		22	3.65	3.84
		24	3.67	4.01
		26	3.82	4.17
3	70	18	3.57	3.90
		20	3.72	4.04
		22	3.84	4.21
		24	3.88	4.38
		26	4	4.55
4	80	18	3.94	4.24
		20	4.07	4.40
		22	4.22	4.57
		24	4.37	4.74
		26	4.52	4.92
5	90	18	4.27	4.61
		20	4.41	4.77
		22	4.56	4.93
		24	4.71	5.10
		26	4.88	5.28
6	100	18	4.6	4.97
		20	4.75	5.13
		22	4.9	5.30
		24	5.05	5.47
		26	5.22	5.64

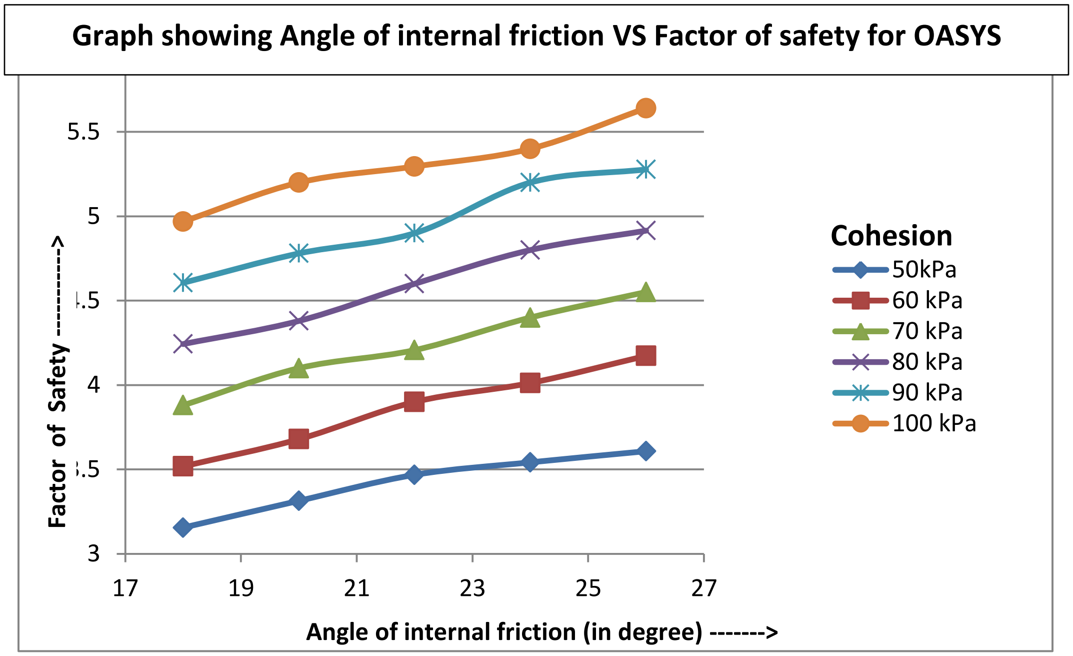


Fig. 3.24 Variation of Factor of safety with angle of internal friction for different cohesion values in OASYS

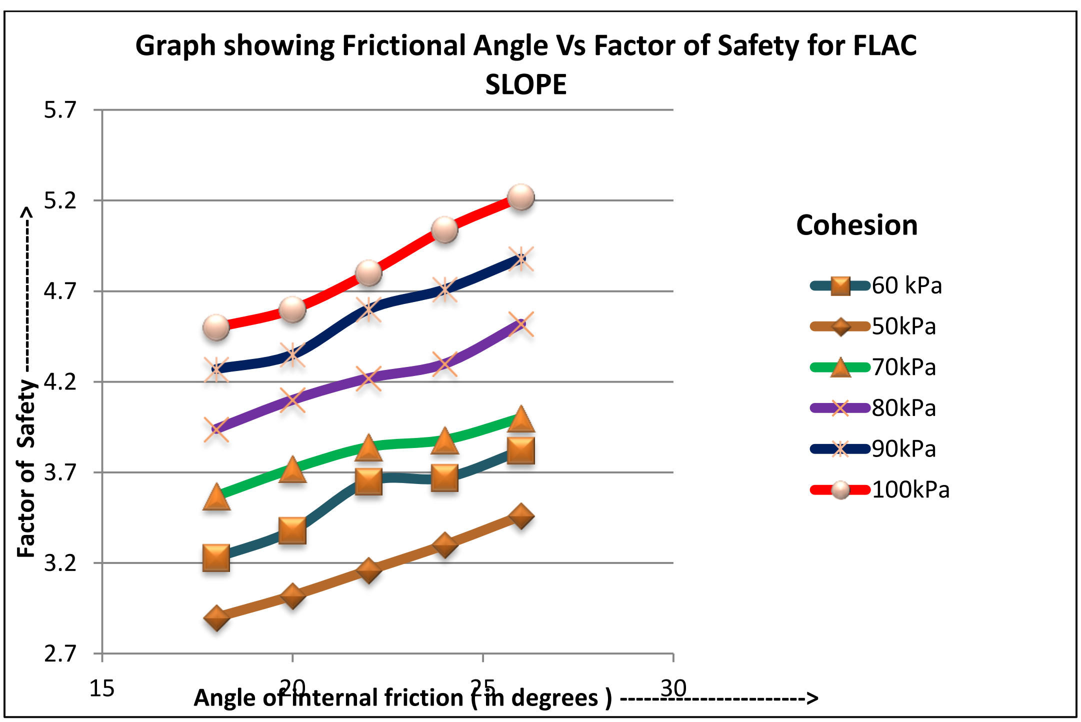


Fig. 3.25 Variation of Factor of safety with angle of internal friction for different cohesion values in FLAC SLOPE

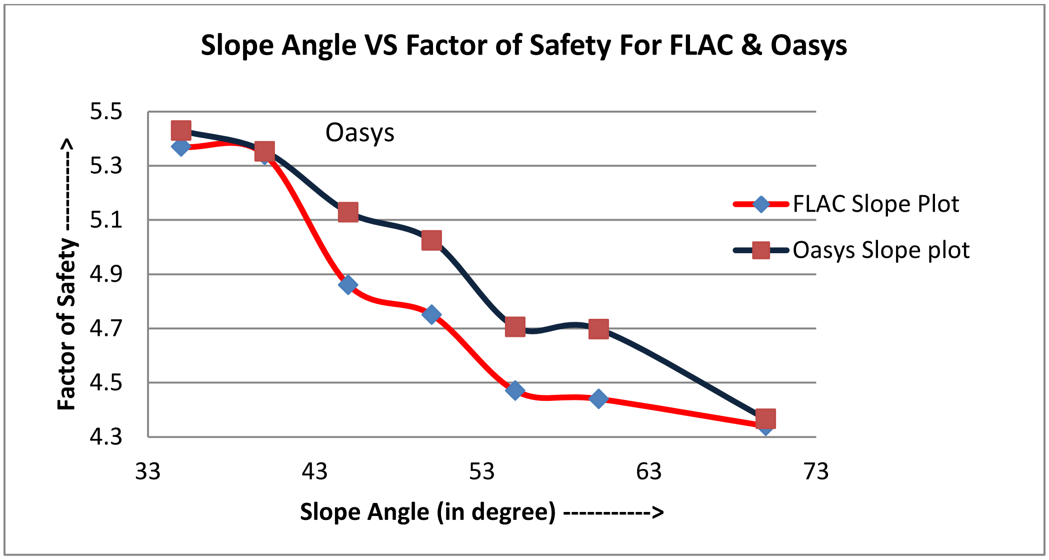


Fig. 3.26 Variation of Slope Angle Vs Factor of safety in FLAC SLOPE & OASYS

3.12 RESULTS & DISCUSSIONS

- From the Tri-axial test the Cohesion & Angle of internal Friction were found to be 82kPa & 24.49^0 respectively.
- It can be concluded from the Table 3.7 that on increasing slope angle of the pit, the factor of safety decreases from 5.37 to 4.34 in case of FLAC SLOPE and from 5.43 to 4.37 in case of OASYS.
- It can be seen from Table 3.7 that at 45^o slope angle, the factor of safety obtained from FLAC SLOPE and OASYS are 4.86 & 5.18 respectively, which is quite safe.
- Table 3.8, shows the parametric studies of the benches and shows the effect of change in internal friction & cohesion on factor of safety.
- From the Figures 3.24 & 3.25, it is observed that for same angle of internal friction, higher the cohesion value more is the factor of safety and for a particular cohesion value, the factor of safety increases with increase in angle of internal friction.

- All the Figures from 3.15 to 3.23, shows different models generated with both the software's (i.e. FLAC SLOPE & OASYS) by varying cohesion & angle of internal friction & the corresponding Factor of safety.
- Fig. 3.26 shows the change in factor of safety with slope angle in FLAC SLOPE and OASYS. It shows that on increasing slope angle, the factor of safety decreases in both cases.

CHAPTER - 4

CONCLUSIONS

CHAPTER - 4

CONCLUSIONS

4.1 CONCLUSIONS

Based on the Numerical modelling the following conclusions can be made:

1. The analysis results specify that the factor of safety changes with slope angle.
2. Parametric studies suggest that stability increases on increasing both cohesion & angle of internal friction. This happens because on increasing cohesion the binding property of the material increases which makes the slope stable.
3. It can be concluded that by updating the search radius & angle of rotation in OASYS the factor of safety increases, whereas in case of FLAC SLOPE the factor of safety changes on changing the resolution of numerical mesh.
4. Factor of safety varies from 5.37 to 4.34 for slope angle of 35° to 70° with a cohesion value of 82 kPa in FLAC SLOPE. Similarly, it varies from 5.43 to 4.37 in case of OASYS.
5. It was seen that the result obtained in both the software's are different. This is due to:
    - The difference in results indicates that both the software used in this case uses different analysis technique.
    - A higher value of factor of safety is obtained in case of OASYS because it considers the failure surface to be moving in a direction lying in the arc of a circle. But in FLAC SLOPE failure may occur in any direction, so lesser factor of safety is obtained.
    - The grid size in the FLAC SLOPE might be another reason which accounts for the change in results.

4.2 SCOPE FOR FUTURE WORK

- In this Project work, only angle of internal friction & Cohesion have been considered for parametric studies. But the study can be expanded to slope angle of individual benches where benches having different heights.
- While calculating Factor of safety the investigation assumed certain condition i.e. The effect of geological disturbances and water table is negligible. The study can be carried out with other typical parameters like effect of blasting, geological disruption & presence of water table.
- Present study was based on three coal seams only, but can be carried out with all the seams using other software.
- For designing stable slope, other software's like Galena, Slide, RocFall & UDEC etc. can be used for predicting the sensitivity.

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